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SHOULDER INJURIES IN ADOLESCENT ELITE HANDBALL PLAYERS

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To Mia, Hampus and Mattea

If you can keep your head when all about you
Are losing theirs and blaming it on you,
If you can trust yourself when all men doubt you,
But make allowance for their doubting too,
Yours is the Earth and everything that's in it,
And - which is more - you'll be a Man, my son!

Rudyard Kipling

ABSTRACT

Background: Handball is a physically demanding sport that includes jumping, running, side-cutting movements and frequent throwing. A high prevalence of shoulder problems and pain has been reported in adult handball players but the research on adolescent elite players is scarce. Several factors have been associated with shoulder injuries in handball players, but strong scientific evidence is lacking for most of the suggested risk factors.

Objectives: The objectives of this thesis were to determine the prevalence of shoulder problems in adolescent elite handball players, to present reference values of shoulder strength in adolescent elite handball players and to investigate if adolescent elite handball players with pre-season shoulder weakness, decreased shoulder range of motion (ROM), scapular dyskinesia or deceased joint position sense (JPS) have higher shoulder injury rates compared to players without these characteristics.

Methods: The thesis is based on data from the Karolinska Handball Study, a prospective cohort study with, in total, 471 Swedish adolescent elite handball players (622 player seasons) from 10 handball-profiled secondary schools. At baseline the players filled in a questionnaire and then shoulder strength, JPS, ROM and scapula dyskinesia were measured. Thereafter, the players were monitored on a weekly basis regarding injuries and amount of handball training and matches. Prevalence ratios (PR) and hazard rate ratios (HRR) were calculated and any differences in shoulder strength between sex, playing position, school grade and playing level as well as side-to-side differences in shoulder strength were evaluated using t-tests.

Results: In total, 110 players (23%) reported substantial shoulder problems during the competitive season. The prevalence was higher among females (PR 1.46, 95% 1.04-2.06) and backcourt players compared to 6-metre players (PR 1.58, 95% CI 1.08-2.32). Male players were stronger in all measures, regardless of normalisation to bodyweight or not ($p<0.0001$). Both male and female players were stronger in the dominant arm ($p<0.001$). In general, wing players and backcourt players were stronger than line players and goalkeepers. In females, the HRR for new shoulder injuries in players with lower isometric external rotational strength (IER) was 2.37 (95% CI 1.03-5.44), lower isometric internal rotational strength (IIR) 2.44 (95% CI 1.06-5.61), and in those with scapular dyskinesia 1.53 (95% CI 0.36-6.52). In males, the HRR for weaker IER was 1.02 (95% CI 0.44-2.36), for lower IIR 0.74 (95% CI 0.31-1.75), and for scapular dyskinesia 3.43 (95% CI 1.49-7.92). There were no associations between new shoulder injuries and deficits in ROM or JPS.

Conclusions: The prevalence of substantial shoulder problems in adolescent elite handball players is higher among females and backcourt players. Male players are stronger than female players in terms of both absolute strength and when normalised by bodyweight. In both male and female players, wing players and backcourt players are, in general, stronger than line players and goalkeepers when normalised by bodyweight. Male players with pre-season scapula dyskinesia, and female players with pre-season internal or external rotation shoulder weakness, had an increased shoulder injury rate.

LIST OF SCIENTIFIC PAPERS

I. Asker M, Holm LW, Källberg H, Waldén M, Skillgate E. Female adolescent elite handball players are more susceptible to shoulder problems than their male counterparts. Knee Surg Sports Traumatol Arthrosc. 2018 Jul;26(7):1892-1900.

II. Asker M, Holm LW, Cools AM, Källberg H, Waldén M, Skillgate E. Shoulder strength differs among playing positions in adolescent elite handball players – reference values from 341 healthy players (under review in Knee Surgery, Sports Traumatology, Arthroscopy, September 2019).

III. Asker M, Waldén M, Källberg H, Holm, LW, Skillgate E. Pre-season clinical shoulder test results and shoulder injury rate in adolescent handball: a prospective study on female and male elite players. J Orthop Sports Phys Ther. July 2019. In print.

OTHER PAPERS AND BOOK CHAPTERS BY THE AUTHOR RELEVANT TO BUT NOT INCLUDED IN THE THESIS

Peer-reviewed articles:

Asker M, Waldén M, Källberg H, Holm LW, Skillgate E. A prospective cohort study identifying risk factors for shoulder injuries in adolescent elite handball players: the Karolinska Handball Study (KHAST) study protocol. BMC Musculoskelet Disord. 2017 Nov 22;18(1):485.

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Book chapters:

Asker M, Cools A, Whiteley R. Shoulder assessment in handball players. In Laver, Landreau, Seil, Popovic. Handball Sports Medicine: Basic science, injury management and return to sport. Springer 2018, pp 461-480.

Asker M, Møller M. Training load issues in young handball players. In Laver, Landreau, Seil, Popovic. Handball Sports Medicine: Basic science, injury management and return to sport. Springer 2018, pp 583-595.

CONTENTS

LIST OF ABBREVIATIONS

ACL	Anterior cruciate ligament
AIMS	Athletic identity measurement scale
BMI	Body mass index
CI	Confidence interval
EER	Eccentric external rotation
EHF	European Handball Federation
GIRD	Glenohumeral internal rotation deficit
HHR	Hazard rate ratio
HHD	Hand-held dynamometer
IABD	Isometric abduction
ICC	Intra-class correlation
IER	Isometric external rotation
IHF	International Handball Federation
IIR	Isometric internal rotation
JPS	Joint position sense
KHAST	Karolinska Handball Study
MDC	Minimal detectable change
MRI	Magnetic resonance imaging
N	Newton
OSTRC	Oslo Sports Trauma Research Center
PR	Prevalence ratio
RCT	Randomised controlled trial
ROM	Range of motion
SD	Standard deviation
SEM	Standard error measurement
SMS	Short message service
STROBE	Strengthening the reporting of observational studies in epidemiology
TRIPP	Translating research into injury prevention practice

1 BACKGROUND

Handball was introduced as an Olympic sport in Munich 1972 for men and in Montreal 1976 for women (1). It is one of the most popular sports in Europe, especially in Scandinavia. There are currently 201 official full member federations under six confederations in the International Handball Federation (IHF) with more than 27 million players in almost two million teams (1). Handball is particularly popular in Europe, and the European Handball Federation (EHF) consists of 52 member federations (2). The handball court is 20×40 metres, with a half-circle-shaped designated goalkeeper area in front of the goals (3). A handball team consists of six field players and one goalkeeper. The field players are divided into three backcourt players (right and left backcourt and mid-court), two wing players (left and right) and a line player (pivot). For adult and junior players, a match consists of two 30-minute periods and for the younger players a match is 2×25 minutes (age 12-16) or 2×20 minutes (age 8-12) (3). There are around 130,000 registered players in Sweden (4). At the start of this project there were 38 national secondary schools with an elite handball profile certified by the Swedish Handball Federation (SHF) with a total of approximately 1,100 players in the age range of 15 to 19 (4).

1.1 Handball

1.1.1 General physical demands

Handball is a sport with high physical demands that requires a combination of aerobic and anaerobic capability in order to perform all the game's requirements. The game consists of high-intensity bursts, side-cutting moves, and jumping, high velocity throws, blocking and in addition a great deal of physical contact with the opponent. This is in addition to the aerobic and anaerobic fitness requires strength, speed, power and agility from the player (5-9). However, the literature on match demands in adolescent handball is scarce. Chelly et al. reported that during a 2×25-minute adolescent male handball match the players cover on average around 1,777(+-264) metres, equal to 35.5 metres per minute, of which 10% consisted of high intensity running and 5% at maximal speed (5), while for 16% of the time the players stood still. This in comparison to reports from studies on adult female elite players who on average cover 4,002 (+-551) metres per game, equal to 66.7 metres per minute and adult male elite players 3,627 (+-568) metres, equal to 60.5 metres per minute (6, 7, 9). The percentage of high intensity running is similar in adult male elite players (8% of the total distance covered) as in adolescent male players, while adult female elite players have been reported as only 2.5% of the total distance covered consisting of high intensity running (5-7, 9).

1.1.2 Playing position-specific demands

The demands on the handball players differ depending on playing position. To date, no studies have reported differences in physical demands between playing positions in adolescent handball. Since the tactical parts in adult handball are similar to adolescent handball, the playing position differences seen in adult handball are potentially similar in adolescent handball. In adult male players, backcourt players make the most of the high velocity throws and passes done during a match compared to wing and line players, while line players perform more screenings, tackles and clasping compared to wing and backcourt players (6-8). In defence, line players often play mid-defence, which includes more blocking, screening and tackling compared to the wing players (8).

1.1.3 Shoulder-specific demands

A fundamental element of handball is frequent throwing, which puts a great demand on the shoulder (1, 5-8, 10). During a handball throw angular velocities around 5,000°/sec in the glenohumeral joint have been reported, which equals almost 14 full turns in the glenohumeral joint in a second (11, 12). Reports on throwing frequency in adolescent handball are scarce, and only one study has described this aspect in detail. Chelly et al. reported that adolescent male players on average perform 100.9 passes and 10.1 shots during a 2x25-minute game (5), which is similar to what has been reported in adult elite players, who perform 18-94 passes and 3-11.4 shots during a game, depending on playing position (8). Similarly, the literature describing the amount of handball throws performed during training sessions is also scarce. Adult male players have been reported to throw an average of 487 handball throws (413 passes and 74 shots) per week during training (13), while adolescent males have been reported to perform 121-154 handball throws per training session (60 minutes) and adolescent females have been reported to perform 113-129 per training session (60 minutes) (14). There are also few reports on ball velocities in handball throws in adolescent players. Even though one study has reported an average throwing velocity as high as 108 km/h in adolescent male players, most studies have reported that adolescent male players' throws involve a ball speed between 72-86 km/h (15-18) and female players between 65-83 km/h (19, 20).

As with other overhead throws, e.g. baseball pitching or cricket bowling, handball throwing is a rapid and complex action including a distinctive whole-body, proximal to distal motion. Handball throwing can be generally divided into three different types of throws; the jump throw, standing throw with a pre-running phase, and standing throw without a pre-running phase. Moreover, the throwing motion can be divided into a whip-like or a circle-like motion. Finally, the handball throw can be performed with an overhead arm motion or an "underhead" motion, i.e. side throw (10).

With the exception of the side throw, all other throws share the same kinematics and are divided into six different phases; wind-up, stride, arm cocking, acceleration, deceleration and follow-through (21, 22) (Figure 1). First, there is the wind-up phase, which primarily involves a rotation of the pelvis and the trunk. This is followed by the stride phase, where the player externally rotates and abducts the throwing arm to position the arm in the throwing position. Next is the cocking phase, where the player initiates the throwing motion. In the cocking phase, the arm is maximally externally rotated in the throwing position. Subsequently, the player rotates the pelvis and trunk followed by internal rotation of the shoulder and extension of the elbow (acceleration phase). The acceleration phase is followed by the deceleration phase, where the player continues the internal rotation and horizontal abduction of the shoulder and the elbow extension. This is followed by the follow-though phase wtih continued trunk flexion, shoulder adduction and horisontal adduction (Figure 1). Even though there are some differences in the handball throws compared to throws in other overhead sports, e.g. baseball pitching, these phases are also seen in these types of throw (22).

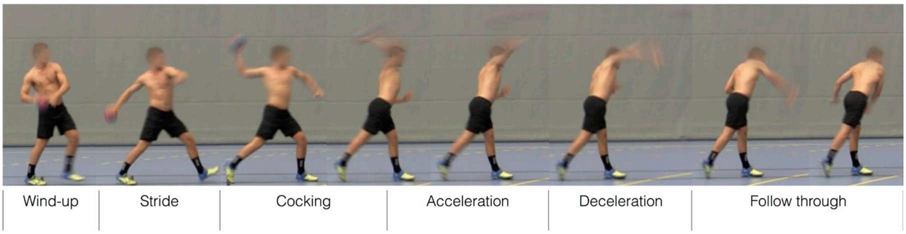

Figure 1. *Phases during a handball throw. (photo: Markus Waldén, used with permission).*

The types of throw create different types of demand on the shoulder girdle. The whip-like throw involves a higher degree of external rotation in the glenohumeral joint during the cocking phase compared to the circle-like throw (23). In contrast, during the circle-like throw there is a higher rotational and flexion velocity in the trunk compared to the whip-like throw (23). Highest stress on the shoulder has been reported to occur during the cocking phase and deceleration phase (23, 24).

Previous studies have shown that the greatest ball velocity is achieved in the standing throw with run-up compared to standing throw with no run-up and jump throw (10). The circular wind-up throw produces a higher throwing velocity compared to the whip-like throw; however, the whip-like wind-up throw has been reported to have a lower total throwing time compared to the circular wind-up throw (23). One suggestion for the greater ball velocity in the run-up throw is the correlation between the velocity of centre of mass in the goal-directed movement and ball velocity (25).

1.1.4 Shoulder characteristics in handball

When a movement, e.g. throwing, is performed repeatedly at a certain magnitude for a long time, specific responses are evoked in which certain biological structures adapt to enable the handball player to adequately tolerate the load. These sport-specific adaptations affect musculoskeletal and myo-fascial structures, bones and ligaments. In general, sport-specific adaptations enhance the quality of sport-specific movement patterns and sport-specific performance. Even though most studies investigating shoulder adaptations in throwers are performed on baseball pitchers and other overhead athletes, there are some studies on handball players (26-34).

1.1.4.1 Shoulder strength

Several studies have reported shoulder strength profiles on handball players, but few studies have focused on adolescent players (35-39). Achenbach reported that there was a side-to-side difference in isometric internal rotation strength in favour of the non-dominant shoulder in male and female youth elite players (aged 14.1), while for isometric external rotations strength there was a favour for the dominant shoulder (39). Furthermore, male players were stronger in terms of absolute strength, but only in isometric external rotation strength when normalised by bodyweight. Van Cingel et al. reported a side-to-side difference in both internal and external rotation strength in favour of the dominant shoulder in adolescent female players (aged 17.6). The players were also stronger in the dominant shoulder compared to a control group of physical therapy students who were active in non-overhead sports (aged 20.3) (38). A previous study on French adolescent female players (aged 18.0) showed a side-to-side difference in favour of the dominant shoulder, however when compared to a group of non-overhead athletes the only strength difference reported was that the handball players were stronger in eccentric isokinetic internal rotation strength at 60°/s (36). In a previous study on Brazilian adolescent players, Andrade et al. reported that male players aged 14-18 were stronger in concentric internal and external rotation strength but no differences were seen in players aged 12-13 (35). These findings on sex-related differences and side-to-side differences are in line with previous research on adult players (40-45).

1.1.4.2 Glenohumeral range of motion

Another common adaptation seen in handball players is a side-to-side difference range of motion (ROM) in the throwing shoulder compared to the non-throwing shoulder (26, 38, 39, 40, 44, 46, 47). The mechanism of these changes in ROM is probably multifactorial and caused by adaptations of several different biological structures. Achenbach et al. reported that adolescent male and female players (aged 14.1) have greater external rotation ROM in the dominant shoulder compared to non-dominant shoulder. They also showed that male players have less total ROM in the dominant shoulder compared to female players, and less internal rotational ROM. However, male players had greater external rotational ROM (39).

Nevertheless, most of these sex-related differences in ROM could not be reproduced in a more recent study carried out by the same authors on a similar sample of adolescent players (46), where the only sex-related difference was less internal rotational ROM in male players. Furthermore, the latter study did not confirm the side-to-side differences in total ROM, while the side-to-side differences in external and internal rotational ROM were confirmed (46). Cingel et al. reported that female adolescent handball players (aged 17.6) had a greater external rotational ROM. They also had a greater total ROM in the dominant arm compared to the non-dominant arm. These side-to-side differences could not be found in a control group consisting of 30 non-overhead sports participants (38). In contrast to this, Quadros et al. reported that Brazilian adolescent female players (aged 15.6) had a greater internal rotational ROM in the dominant side compared to the non-dominant side, but no differences were found in external rotational ROM (47). No analyses were presented for the total ROM in that study. These side-to-side differences in adolescent players are in line with the results for adult players (40, 45, 48, 49), indicating that these alterations in ROM already exist in adolescent players.

1.1.4.3 Scapular dyskinesia and shoulder posture

Altered scapular movement (scapular dyskinesia) in throwing athletes was first introduced by Kibler, who described three different types of scapula dyskinesia: i) defined as a prominent inferior angle of the scapula during, ii) defined as a prominent medial board of the scapula and iii) defined as a prominent superior angle of the scapula (50). Previous studies have reported a two-fold higher prevalence of scapula dyskinesia in overhead athletes compared to non-overhead athletes (51) but the scientific evidence for the importance of scapular dyskinesia for future shoulder injuries in overhead athletes is lacking (52). Moreover, altered shoulder posture and side-to-side scapula position are common in overhead athletes (53, 54).

1.1.4.4 Osseous adaptations – retrotorsion of the humerus

Achenbach reported that male adolescent players had a larger retrotorsion of the humerus, on average 4°, in the dominant arm compared to the non-dominant arm, while no significant difference was seen in female adolescent players (on average 2°) (46). Pieper et al. reported that male professional handball players had on average a 9.4° larger retro-torsion of the humerus in the dominant arm compared to the non-dominant arm (26). These results are in line with the results from a recent study on German collegiate handball players (aged 18-29), who reported a larger retro-torsion in the dominant arm, 11.7° versus 9.2° (33). Similar osseous adaptations have also been reported in other overhead athletes (27-32, 55).

1.1.4.5 Radiological findings in handball shoulders

There is, to the best of my knowledge, no study that has reported radiological findings in adolescent handball shoulders, except for the studies measuring the retrotorsion of the humerus. In adult male players it has been reported that 93% of the players have abnormal magnetic resonance imaging (MRI) findings in the throwing shoulder, although only 37% of the investigated players had any symptoms (56). Notably, in a control of non-overhead volunteers the prevalence of abnormalities in the dominant shoulder was 80%. However, the handball players had, on average, seven abnormities in the throwing shoulder while the control group had two. Moreover, the handball players had significantly more rotator cuff abnormalities (such as tendinopathy and partial tears) as well as supralateral glenohumeral head abnormalities (oedema, cysts and defects) and labrum abnormalities in the throwing shoulder compared with the control group. The most common finding in the throwing shoulder in the handball players was supraspinatus abnormality, which was reported in as much as 83% of the players (56). In a follow-up study on the same sample 15 years after retirement, the handball players still had, on average, seven MRI abnormalities and the only abnormality that decreased over time was superolateral humeral head oedema/defects (57). In contrast, the number of abnormalities of the humeral head had increased. Since the majority of the players did not have any symptoms and since this study was of a cross-sectional design, it is unclear how these findings are associated to current and future shoulder symptoms (57). There could be a possible relationship with shoulder symptoms, but these findings could also merely be normal adaptive findings in the handball shoulder.

Although no studies have reported radiological abnormalities in adolescent handball players, several studies have been performed on other adolescent overhead athletes. Johansson et al. reported that in asymptomatic adolescent elite tennis players (aged 17.4) 29% and 14% have MRI findings of infraspinatus and supraspinatus tendinosis, while no tendinosis was found in the non-dominant shoulder (58). No difference in shoulder strength was seen between those with and without tendinosis in this study. These findings are somewhat lower than what has been reported in recent studies in asymptomatic adolescent baseball players, where Pennock et al. reported that 52% had MRI abnormities and 25% of the players had partial tears of the rotator cuff (59) and Nguyen et al. that 90% of the players had supraspinatus tendinosis, 62% had infraspinatus tendinosis and 74% had superior labral tears (60).

1.2 Injuries in handball

1.2.1 Epidemiology in sports medicine

It has been advocated that sports injury prevention research should follow four chronological steps, i.e. the sequence of prevention of sports injuries (61). In this model, created by van Mechelen, epidemiology plays an important role and prospective cohort studies and randomised controlled trials (RCTs) are important study designs. The first step is to describe the magnitude of the problem in terms of incidence and severity. The second step is to identify the underlying risk factors and injury mechanisms. The third step is to introduce preventive measures based on the knowledge obtained in the second step. Finally, the effect of the preventive measures is evaluated by repeating step one, or preferably by carrying out an RCT, as added later in the model (61). Subsequently, the sequence-of-prevention model was expanded by Finch, who added two steps and named it the Translating Research into Injury Prevention Practice (TRIPP) framework (62). The extra steps emphasise the fact that only interventions that are implemented in real-life sports surroundings can prevent sports injuries.

1.2.2 Injury rates

Historically, in sports medicine, the main objective with epidemiology studies has been to assess the injury incidence. Results are preferably presented as number of injuries (numerator) per 1,000 hours of participation (denominator), which denotes time at risk. Nevertheless, in some sports and for some injury types, especially overuse injuries, merely focusing on the incidence of new injuries may lead to an inability to describe the whole spectrum of overuse-related injuries and long-lasting complaints (63, 64). To handle this risk of underestimation of overuse injuries, the tip-of-the-iceberg phenomenon, a few years ago a different way to report injury rates was therefore introduced; using the proportion of athletes who are affected by the sports related problem (for instance shoulder problems) at a given time i.e. prevalence (63, 64).

1.2.3 Injury registration

One key element in epidemiological studies is the registration and classification of the outcome or event. In sports medicine classification of the outcome often equals the definition of an injury. In order to capture all injuries occurring during a time period the registration method is highly important. Historically, several methods have been used, and each method has its own strengths and weaknesses. With injury registration via a medical team, researchers will obtain more details regarding the injury and potentially a more specific diagnosis (65-70). One limitation is that not all teams or individual athletes have a medical team, especially in younger age groups and in lower amateur divisions. Another method is registration via the coach (71, 72). The obvious strength with this method is that the coach is present at all matches and training sessions. One potential limitation is, however, that coaches often have several other things to take care of before, during and after the match or training session, and might not prioritise the injury registration. Another weakness with coaches' reporting is the potential risk of under-reporting because athletes may not want to tell the coach about an injury, especially with overuse injuries.

In recent handball studies, injuries have been self-reported by players in weekly electronic questionnaires distributed with short message services (SMS) or e-mail (40, 44, 64, 73-75). The main strength with this method of distribution is that researchers can reach the athlete quite easily and can collect data frequently, for instance on a weekly basis. A weakness with self-reported injuries is that only limited information regarding specific diagnoses is obtained (40, 44, 64, 73-75). Furthermore, some studies have used data from insurance claim registers (76). A weakness is, depending of the research objectives, the risk of underestimation, since not all injuries are reported to the insurance company, especially not overuse injuries and minor acute injuries (76).

How often the injury registration should take place is a further factor to consider when designing the injury surveillance. It is preferable that the injury form is completed as soon as possible after the match or training session (67, 68, 77) and sending forms on a weekly or monthly basis is common. Depending of the definition of injury and the injury of interest, the frequency of injury registration will have more or less impact of the risk of bias in the study. If the data collection is scheduled more often there is a lower risk of injury misclassification due to the ability to remember if an injury occurred, especially for minor injuries. However, frequent self-reporting of injuries where the report should be filled in regardless of whether an injury occurred or not, could potentially decrease the response rate and introduce a risk of selection bias in analyses of potential risk factors (40, 44, 64, 73-75). Strategies on how to handle potential missing or unclear data are therefore also highly important in the study design.

1.2.4 Injury definition and classification

In studies on sports injuries, researchers often strive to classify injuries into being an acute or an overuse injury, and with a specific diagnosis, since they may have different aetiology and risk factors (52, 61, 63, 67, 68, 77). It is, however, not always easy to classify the injuries, especially if they are self-reported. Some types of sports injuries are easier to classify, for instance severe specific diagnosis as anterior cruciate ligament (ACL) tear or shoulder dislocation were athletes have to seek care. Other injuries are harder to classify, especially if no medical support around the athlete is involved in the study. In these cases, injuries are often classified into topographical areas. Traditionally, different definitions have been used to define an injury, for instance if the athlete sought medical attention, had to quit the activity, or missed the next training session or match (39, 65, 66, 68, 70, 72, 73, 78, 79). Importantly, there are now consensus statements regarding injury definitions and data collection methods in team sports such as football and rugby (78, 80). Unfortunately, there is not yet any similar research guideline for handball or other indoor team sports that could be used.

Recent studies have shown that just using a time-loss definition for injuries may not be suitable, especially if monitoring overuse injuries is the objective, since many athletes continue to participate in their sport as long as they can perform even though they have overuse injuries (63, 64). Clarsen et al. have developed and presented a questionnaire, the Oslo Sports Trauma Research Center (OSTRC) overuse injury questionnaire with the purpose of more effectively capturing overuse injuries (64). The original questionnaire includes four questions for each topographical area (shoulder, lower back, knee and foot/ankle), where each answer corresponds to a certain score summing up to a total score between 0-25 for each question, and a total score between 0-100 for each topographical area. When comparing injury registration using this questionnaire to the traditional methods, when injuries are reported using a time-loss definition, they showed that the OSTRC overuse injury questionnaire would significantly capture more injuries (64). Instead of presenting an incidence rate per 1,000 hours, Clarsen et al. defined injury as having a season average score of 40 or higher on the OSTRC overuse injury questionnaire (40). The players answered the questionnaire every second week and the average score was calculated by dividing the total score that the player reported during the season (30 weeks) with the number of questionnaires reported. Another common outcome based on the same questionnaire is, instead of a specific injury definition, shoulder problems and substantial shoulder problems, which are based on whether the player reports having reduced performance or practice due to the shoulder problems (40, 44).

1.2.5 Injury incidence

Handball is highly associated with injuries, both in adult and adolescent players (65-68, 70, 72-74, 79, 81, 82). Handball has consistently been one of the top three to eight sports in the Olympic Summer Games in terms of the proportion of athletes who receive injuries, where 18-27% of the players are injured during the games (67, 82-84). The injury rates reported from studies in adult players during the competitive handball season range from 15-31.7/1,000 match hours and 0.24-3.4/1,000 training hours (70, 73, 79, 85, 86). The injury rates during tournaments are higher and range from 82.1-145/1,000/1,000 match hours (67, 68, 81, 87). Moreover, in a recent study analysing Swedish insurance data, handball was the team sport with the highest incidence of reported injuries per 1,000 athletes, with 63.4 reported injuries per 1,000 athletes in females and 57.2 in males (76).

The injury rates reported in adolescent handball are similar to those reported in adults, with reported injury rates between 8.3 and 156.0 injuries/1,000 match hours and between 0.6 and 3.7 injuries/1,000 training hours (39, 65, 66, 72, 73, 75, 79, 88-92). One study stands out in terms of injury rates, where 156 injuries/1,000 match hours was reported. This study was based on data from three tournaments, which can explain the exceptional high injury rate (88). The injury risks are generally 5 to 20 times higher during matches compared to training. A summary of reported injury rates in adolescent handball is presented in Table 1.

To the best of my knowledge, only four studies have investigated sex-related difference injury rates in adolescent players (73, 88, 91, 92). Lindblad et al. reported a higher incidence in females aged 5-14, compared to males (91). In contrast, Andrén-Sandberg et al. reported a higher injury rate in males, aged 13-18, while no sex-related differences were found in the age group 10-12 (88). Comparably, Asai et al. reported a higher incidence in males (32.7/1,000 player hours) compared to females (20.1/1,000 player hours), in players aged 13-14 (92) and Møller et al. found that in Under-18 players, males had 1.8 higher risk of injury compared to females. No sex-related differences were found for the Under-16 players (73) (Table 1).

Notably, most of the incidence rates in the studies in adolescent handball are reported using different registration methods and injury definitions, and also different populations of handball players and a different range of follow-up time and period during the handball season, as well as different time eras (ranging from 1982-2019) which potentially result in the widely different incidence and prevalence estimates.

Table 1. Injury rates in adolescent handball.

Authors	Population	Study type	Injury definition	Injury rate – injuries per 1,000 hours
Nielsen & Yde 1988[89]	94 Danish male and female players from one club (aged 7-18)	Prospective	An incident occurring during a handball match or training in the club, causing the player to miss at least one match or one training session	Females Match: 11.4 Training: 2.2 Males Match: 8.9 Training: 1.7
Wedderkopp et al. 1997[65]	217 Danish female players from 23 teams (aged 16-18)	Retrospective	Medical attention and/or time-loss and/or discomfort. Any injury occurring during scheduled games or practices and causing the player to either miss the next game, or practice session, or being unable to participate without considerable discomfort.	Match: 40.7 Training: 3.4
Wedderkopp et al. 1999[66]	126 Danish female players from 22 teams (aged 16-18)	Prospective	Medical attention and/or time-loss and/or discomfort. Any injury occurring during scheduled games or practices, causing the player to either miss the next game, or practice session, or being unable to participate without considerable discomfort.	Match: 23.4 Training: 1.2

Authors	Population	Study type	Injury definition	Injury rate – injuries per 1,000 hours
Olsen et al. 2006[72]	428 Norwegian players from 34 teams (aged 15-17)	Prospective	Injury occurring during a scheduled match or training session, causing the player to require medical treatment or miss part of or rest of the match or training session	Females Match: 10.4 Training: 1.0 Males Match: 8.3 Training: 0.6
Olsen et al. 2006[72]	1080 Norwegian players from 90 teams (aged 15-17)	Prospective	An injury was registered if it occurred during the match, causing the player to require medical treatment or miss part of or rest of the match	Females Match: 14.4 Males Match: 8.3
Møller et al. 2012[73]	211 Danish Under-16 and Under-18 male and female players from 9 clubs	Prospective	Any physical complaint sustained by a player that results from a handball match or handball training causing the player to miss part of or rest of the match or training session.	Females Under-16: Match: 10.8 Training: 2.9 Males Under-16: Match: 11.5 Training: 1.7 Females Under-18: Match 13.0 Training: 2.1 Males Under-18: Match: 17.2 Training: 3.2
Achenbach et al. 2017[39]	279 German male and female players (aged 13-18)	Prospective	Any injury caused by playing handball during training or competition and if it resulted in absence from at least one training session or match	Match: 8.2 Training: 1.0
Møller et al. 2017[75]	679 Danish male and female players from 52 teams (aged 14-18)	Prospective	Shoulder injury in the dominant arm defined as any handball-related shoulder problem irrespective of the need for time loss or medical attention.	Playing hours (match + training): 10.0
Mónaco et al. 2018[79]	133 Spanish Under-14 to Under-18 male players from one club	Prospective	Any injury occurring during a training session or match, and causing an absence for at least the next training session or match	Match: 14.9 Training: 3.7
von Rosen et al. 2018[90]	45 Swedish female and male players from one school (aged 16-18)	Prospective	Any physical complaint that affected participation in normal training or competition or led to reduced training volume, pain, or reduced performance in sport.	Playing hours (match + training): 4.7

1.2.6 Injury location and types of injury

The most frequently reported injuries in adolescent handball are traumatic lower limb injuries, e.g. ankle, thigh and knee injuries, and hand/finger injuries (65, 66, 72, 73, 79, 89, 90, 92, 93, 94) and overuse injuries in the shoulder and lower leg (72, 90, 93). An overview of injury distribution in adolescent handball is presented in Table 2. These injury types and distributions are in line with what has been reported in adult players (67, 68, 70, 81, 83, 85, 87, 95). Only a few studies have reported injury types, i.e. a specific diagnosis, but in the few that have, the majority of injury types are sprains, strains, cartilage injuries, synovitis/bursitis, contusion/haematoma, tendinopathies, fractures, periostisis, knee pain, low back pain and muscle injuries (72, 79, 89). This is also similar to what has been reported in adults (67, 68, 70, 73, 81, 85, 87).

1.3 Shoulder injuries in handball

1.3.1 Incidence and prevalence

Many previous studies on handball have not described the incidence rate of shoulder injuries in relation to the exposure, e.g. per 1,000 hours, but instead reported the number of shoulder injuries and the proportion of the total number of injuries or the prevalence of shoulder pain (40, 44, 48, 65, 67, 68, 70, 74, 85, 94, 96-100). A summary of shoulder injuries and problems in handball is presented in Table 3.

The incidence for shoulder/upper arm injuries in adolescent players is between 0.2-1.44/1000 handball hours (36, 73, 75). The point prevalence of shoulder pain in adolescent players has been reported to be between 7-49% (94, 97, 98, 99) and a one-season prevalence to be between 25-63% (39, 94, 97). Moreover, the average week prevalence of shoulder problems and substantial shoulder problems has been reported to be 17% and 7% respectively (94).

The prevalence of shoulder pain in adolescent players is similar compared to previous studies on adult populations, where the point prevalence of shoulder pain has been reported to be between 20-35% (40, 44, 48, 96). Furthermore, one-month prevalence of 41% (100), season-prevalence of 43-52% (44) and lifetime prevalence of 44-75% has been reported (40, 48, 96). It has also been reported that the average weekly prevalence of shoulder problems in adults is between 22-28% (40, 44, 74) and the average weekly prevalence of substantial problems is between 6-12% (40 44,74), where a higher prevalence has been reported in females (44) (Table 3).

Table 2. Injury distribution in adolescent handball.

	Nielsen & Yde 1988[89]	Wedderkopp et al. 1997[65]	Wedderkopp et al. 1999[66]	Olsen et al. 2005	Olsen et al. 2006[72]	Møller et al. 2012[73]	Møller et al. 2012[73]	Assheim et al. 2018[94]	Mónaco et al. 2018[79]	von Rosen et al. 2018[90]	Asai et al. 2019[92]
Population	94 Danish male and female players (aged 7–18)	217 Danish female players (aged 16–18)	126 Danish female players (aged 16–18)	879 Norwegian female and male players (aged 15–17)	428 Norwegian female and male Under-17 players	152 Danish female and male Under-18 players	194 Danish female and male Under-16 players	145 Norwegian adolescent male players (aged 16–18)	133 Spanish male Under-14 to Under-18 players	45 Swedish female and male players (aged 16–18)	169 Japanese female and male players (aged 13–14)
Study design	Prospective	Retrospective	Prospective	Prospective	Prospective	Prospective	Prospective	Prospective	Prospective	Prospective	Retrospective
Injury definition	Time-loss/ physical complaint	Time-loss/ physical complaint	Time-loss/ medical treatment	Time-loss/ medical treatment	Time-loss/ medical treatment	Time-loss	Time-loss	Physical complaint	Time-loss	Physical complaint	Medical treatment
Anatomical location	Number of injuries	Number of injuries (%)	Number of injuries (%)	Number of injuries (%)	Number of injuries (%)	Number of injuries (%)	Number of injuries (%)	Average weekly prevalence of any problems [c]	Number of injuries per player season	Number of injuries (%)	Number of injuries (%)
Total	37 (100) *	129 (100) **	64 (100) [a]	144 (100)[ab]	118 (100)	117 (100)	148 (100)	-	-	64 (100)	169 (100)
Finger	9 (24)	28 (22)	10 (16)	22 (15)	16 (14)	9 (8)	6 (4)	-	-	1 (1.6)	-
Hand/wrist	-	2 (1.5)	1 (1)	-	-	4 (4)	4 (3)	-	0.15	2 (3.1)	22 (13)
Elbow/under arm	-	10 (8)	9 (14)	-	6 (5)	6 (5)	4 (3)	9%	-	4 (6.3)	6 (3.5)
Shoulder/upper arm	3 (8)	2 (1.5)	0 (0)	11 (8)	5 (4)	13 (11)	13 (9)	17%	0.07	8 (12.5)	7 (4.1)
Head/cervical spine	-	-	3 (5)	11 (8)	5 (4)	5 (4)	2 (1)	-	0.02	3 (4.7)	53 (31.4)
Trunk/abdomen	-	-	-	-	1 (1)	3 (3)	0 (0)	-	-	0 (0)	3 (1.8)
Low back/back	-	-	4 (6)	9 (6)	11 (9)	6 (5)	8 (5)	12%	0.13	5 (7.8)	5 (3.0)
Hip/groin/pelvis	-	-	1 (1)	-	4 (3)	5 (4)	14 (10)	-	-	4 (6.3)	0 (0)
Upper leg/thigh	2 (5)	-	0 (0)	-	3 (3)	6 (5)	2 (1)	-	0.14	9 (14.1)	2 (1.2)
Knee	5 (14)	31 (24)	8 (13)	44 (30)	28 (24)	19 (16)	37 (25)	14%	0.14	11 (17.2)	23 (13.6)
Lower leg	-	-	4 (6)	-	15 (13)	11 (9)	28 (19)	-	-	8 (12.5)	6 (3.5)
Ankle/foot/toes	14 (38)	56 (43)	24 (38)	47 (33)	24 (20)	30 (26)	30 (20)	-	0.21	8 (12.5)	42 (24.9)
Others	4 (11)	-	-	-	-	-	-	-	-	1 (1.6)	-

* Hand, arm and shoulder injuries included in the same category.
** Only includes sprains.
[a] Control group of an RCT.
[b] Only the most common injuries were reported.
[c] Only injuries in shoulders, elbows, knees and low back were measured.

Table 3. Shoulder injuries and shoulder problems in handball.

Authors	Population	Study type	Definition	Results
Seil et al. 1998[85]	186 adult players from 16 German clubs	Prospective	An incident occurring during practice or competition that led to nonparticipation of at least one practice session or one game	7 shoulder/upper arm injuries per 100 players
Møller et al. 2012[73]	211 Danish female and male adolescent players	Prospective	Any physical complaint sustained by a player that results from a handball match or handball training causing the player to miss part of or rest of the match or training session	Incidence of traumatic shoulder/upper arm injuries per 1000 handball hours: Under-18: 0.2, Under-16: 0.3 Incidence of overuse shoulder/upper arm injuries per 1000 handball hours: Under-18: 0.4, Under-16: 0.2
Edouard et al. 2012[36]	16 adolescent players from a French national junior team	Prospective	An injury was registered if the player was unable to take full part in handball activity or match play at least one day beyond the day of injury	Incidence of shoulder injury: 1.07 per 1,000 training hours
Myklebust et al. 2013[48]	179 Norwegian adult female players from 12 teams	Cross-sectional	Shoulder pain	Point prevalence of shoulder pain during pre-season: 36% Life-time prevalence: 58%
Clarsen et al. 2014[40]	206 adult male players from all of the teams of the Norwegian elite series	Prospective	Shoulder pain Shoulder problem* and substantial shoulder problem**	Life-time prevalence of shoulder pain: 75% Current shoulder pain: 32% Average weekly prevalence of any shoulder problems in dominant shoulder: 28% Average weekly prevalence of any shoulder problems in non-dominant shoulder: 7% Average weekly prevalence of substantial shoulder problems in dominant shoulder: 12% Average weekly prevalence of substantial shoulder problems in non-dominant shoulder: 1%
Clarsen et al. 2015[74]	55 adult male players and adult and junior female players.	Prospective	Shoulder problem* and substantial shoulder problem**	Average weekly prevalence of any shoulder problems: 22% Average weekly prevalence of substantial shoulder problems: 6%

Authors	Population	Study type	Definition	Results
Giroto et al. 2015[70]	312 adult male and female players from Brazil	Prospective	Pain of musculoskeletal origin related to the practice of handball and which resulted in interruption of at least one training session or match; or the loss of at least one training session or match; or situations in which medical intervention was needed	Cumulative incidence during one competitive season: Traumatic shoulder injuries F: 9%. M: 3% Overuse shoulder injuries F: 11%. M: 10%
Andersson et al. 2017[44]	329 adult male and female elite players from 23 teams of the two upper divisions in Norway	Prospective[a]	Shoulder pain Shoulder problem* and substantial shoulder problem**	One-season prevalence of pain at baseline: F: 43% M: 52% Current shoulder pain: F 31% M 28% One-week prevalence of any shoulder problems at baseline: F 46% M 49% One-week prevalence of substantial shoulder problems at baseline: F 16% M 13% Average weekly prevalence of any shoulder during a competitive season: F 26% M 20% Average weekly prevalence of substantial shoulder problems during a competitive season: F 9% M 7%
Møller et al. 2017[75]	679 Danish male and female adolescent players	Prospective	Shoulder injury in the dominant arm defined as any handball-related shoulder problem irrespective of the need for time loss or medical attention	Shoulder injury incidence rate 1.4/1,000 playing hours
Oliveria et al. 2017[97]	78 Spanish male and female adolescent players	Retrospective	Shoulder pain	Point prevalence of shoulder pain: 49% One-year prevalence: 63%
Sommervold & Østerås 2017[99]	105 Norwegian female adolescent players	Prospective[a]	Shoulder pain	Point prevalence of shoulder pain at baseline: 25% Average point prevalence during the competitive season: 30%

Authors	Population	Study type	Definition	Results
Aasheim et al. 2018[94]	145 Norwegian adolescent male players	Prospective	Shoulder pain Shoulder problem* and substantial shoulder problem**	One-season prevalence of injury or pain at baseline: 38% Point prevalence of shoulder injury or pain at baseline: 20% Average weekly prevalence of any shoulder problems during a competitive season: 17% Average weekly prevalence of substantial shoulder problems during a competitive season: 7%
Lubiatowski et al. 2018[100]	87 adult male elite players from four teams from the first and second Polish division	Cross sectional	Pain was defined as reporting at least 2 on a 0-10 NRS with duration of at least 1 week within the past month	One-month prevalence of shoulder pain: 41%
Achenbach et al. 2019[39]	138 German male and female adolescent players	Prospective	Injury defined as reporting an average severity scores for the standardised injury questionnaire and the WOSI of 20% of the maximum score at some point during the 7-months season	Pain or overuse symptoms in the dominant shoulder during 7 month follow-up: 26% Score >20% of the maximum WOSI during 7 month follow-up: 12%
Asai et al. 2019[92]	169 male and female adolescent players	Retrospective	Injury occurring with a clear onset during the match and causing the player to require medical treatment at the venue's medical rooms	Shoulder injury rate: 1.09 per 1,000 player-hours

F Female, M Male, WOSI Western Ontario Shoulder Index
* Definition of any shoulder problem = any reduced handball participation, training volume or performance, or pain.
** Definition of substantial shoulder problem = moderate or severe reductions in training volume or in performance, or complete inability to participate in handball.
[a] Based on the control group from an RCT.

1.3.2 Injury pattern and risk factors for shoulder injury

Several factors, such as decreased or increased shoulder mobility, shoulder weakness, rapid increase in training load, and scapula dyskinesia, have been suggested to be associated with shoulder injuries in studies of overhead athletes (36, 40, 44, 75, 101-103). However, strong scientific evidence is lacking for the causal effect of most of the suggested modifiable risk factors including the results of common clinical screening methods (52, 104, 105). Even though there are a growing number of observational studies in handball, only a handful of studies have attempted to investigate risk factors for shoulder injuries in adolescent handball. Edouard et al. found that female adolescent players (aged 18) with a low external to internal rotational strength ratio were associated with shoulder injuries (36); this was, however, a small study with only 17 participants and seven events. Similar findings have thereafter been reported in a mixed population of German youth players (aged 14.1), where players who started the handball season with external rotation shoulder weakness or a low external to internal rotational strength ratio had an increased risk of reporting overuse shoulder injuries (39). Moreover, female players with glenohumeral internal rotation deficit (GIRD), i.e. decreased internal rotational ROM on the dominant arm compared to the non-dominant arm, were associated with higher risk of shoulder injury, but no associations were seen in male players (39). Møller et al. found that in a mixed cohort of Danish youth elite players (aged 14-18), those who increased their weekly training load by 60% or more had twice as high a risk of sustaining a shoulder injury during the season compared to those who did not increase their weekly training load of more than 20%. In players with scapular dyskinesia or external rotation shoulder weakness, the risk was twice as high already at a weekly increase in training load of 20% or more (75).

In adult male players in Norway, Clarsen et al. reported that external rotation shoulder weakness or reduced glenohumeral external rotational ROM or scapular dyskinesia were associated with overuse shoulder injuries (40). However, in a more recent study on Norwegian female and male players, increased internal rotational ROM was associated with a higher risk of shoulder injury (44). Forthomme et al. found that glenohumeral internal rotation shoulder weakness was associated with a higher risk of traumatic shoulder injuries in French adult male players, but no association was found between external rotation weakness and shoulder injuries (43).

1.3.3 Risk factors for shoulder injuries in other overhead sports

The repetitive use of the shoulder with the hand above the head is a common feature for overhead athletes regardless of sport or discipline. Consequently, the mechanisms behind overuse-related shoulder injuries may not differ extensively among overhead athletes. In a recent systematic review, all considered potential risk factors for shoulder injury had limited evidence. Moreover, most of these factors were non-modifiable (e.g. sex) (52).

In men's baseball, limited evidence has been reported for an increased risk of overuse shoulder injuries during matches compared to training, while the opposite has been reported in women's softball and volleyball (52). Moreover, in men's baseball, women's volleyball and men's and women's lacrosse higher rates of traumatic shoulder injuries have been reported during matches compared to training, while no differences have been reported in women's softball (52). In male high school and college lacrosse players, increased risk of shoulder injuries have reported in male compared with female players. Same sex-difference has been reported in college water polo (52). In Japanese youth baseball pitchers, training more than 16 hours per week was associated with higher injury risk, as was history of shoulder pain or elbow pain (52). Having decreased total external and internal rotational range of motion in the dominant shoulder compared to the non-dominant shoulder has been suggested as a risk factor for shoulder injuries in professional baseball pitchers (52). In addition, lack of humeral torsion has been reported as a risk factor for shoulder injuries in baseball pitchers (52). Notable, most of these studies lack confounding controlling (52).

2 AIM OF THE THESIS

2.1 General aim

The general aim of this thesis was to deepen the available knowledge about shoulder injuries in adolescent elite handball players, especially in terms of pre-season clinical testing, and competitive season prevalence and incidence.

2.2 Specific aims

The specific aims were to:

1. Assess the prevalence of shoulder problems, and especially substantial problems, in adolescent elite handball players and to investigate potential differences in sex, school grade, playing position, and playing level (Study I).
2. Assess the intra-reliability and minimal detectable change (MDC) of shoulder strength measures with a handheld dynamometer (HHD), and to present shoulder strength reference values including potential differences in sex, and any sex-specific differences in school grade, playing position and playing level for adolescent elite handball players (Study II).
3. Investigate if female and male elite adolescent handball players with shoulder muscle weakness, deficits in ROM or joint position sense (JPS) or with scapular dyskinesia had a higher rate of new shoulder injuries compared with players who did not have these characteristics (Study III).

3 MATERIAL AND METHODS

3.1 The Karolinska Handball Study (KHAST)

All the studies in this PhD thesis are based on data from the Karolinska Handball Study (KHAST), which is a longitudinal prospective cohort study that was performed by the doctoral student and the supervisors in September 2014 to April 2016. KHAST is one of the largest cohort studies ever, with the aim of investigating risk factors for shoulder injuries in adolescent overhead athletes. The study was conducted in accordance with the Strengthening the reporting of observational studies in epidemiology (STROBE) guidelines (106). The procedure for recruitment of the study population, baseline and follow-up data collection, and ethical approval is described below and in a previous published study protocol (107).

3.1.1 Recruitment

Those eligible for participation in KHAST were male and female handball players enrolled at handball-profiled secondary schools in Sweden certified by SHF that met the a priori set inclusion criteria. The inclusion criteria were: 1) the schools were required to have a capacity for at least 35 handball-profiled students, 2) the schools were required to have an even distribution of male and female players, and 3) the schools were required to be classified by the SHF as being at the highest level. The criteria of minimal number of players were convenient and set to guarantee that a satisfactory number of study participants would be reached during the limited pre-season time window. Moreover, the schools were required to have both female and male players because we wanted to investigate risk factors for both sexes and investigate any sex-related differences in shoulder injuries. Out of the 38 certified schools with approximately 1,100 students at the study start in 2014, ten schools met the inclusion criteria and all these schools accepted to participate in this study. Thus, 471 (54% female) out of a total of 552 eligible players, mean age 16.4 ± 0.9 were included in KHAST; 274 players were included and followed in 2014-2015 and 197 players were included and followed in 2015-2016. One hundred and fifty one of the 274 players who were included and followed 2014-2015 were also tested and followed again in 2015-2016. This resulted in a total of 622 player seasons (out of 703 eligible player seasons) in the total cohort of KHAST (Figure 2) (107).

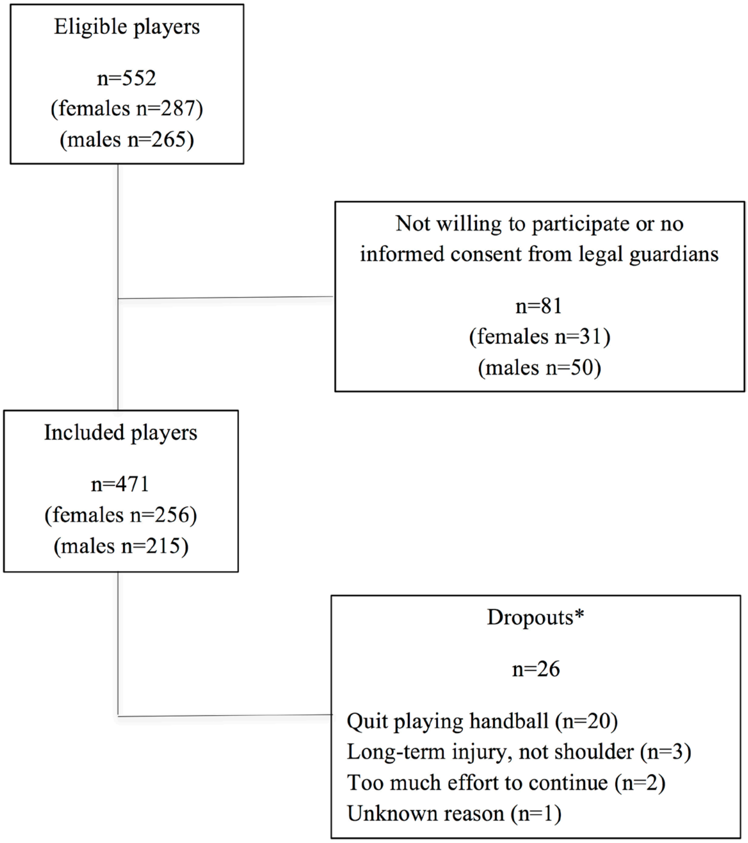

Figure 2. *Study flow chart showing the recruitment and dropout of the Karolinska Handball Study. *Dropouts were included in the analyses and contributed as long they were in the study*

3.1.2 Data collection

3.1.2.1 Baseline questionnaire

The KHAST baseline questionnaire was based on the questionnaire used by Fahlström et al. (108, 109) and the Swedish version of the OSTRC overuse injury questionnaire, which previously have been validated (64, 110). Briefly, the questionnaire focused on playing position, playing level, previous handball experience (match and training history), participation in other sports, and history of shoulder injuries (Appendix A). For the purpose of this thesis, the OSTRC overuse injury questionnaire was modified to collect information about shoulder problems during the past two months and the past season (the original questionnaire focuses exclusively on shoulder problems during the past week). Additionally, in order to measure athletic self-identity, it also included the Athletic Identity Measurement Scale (AIMS) (111). At baseline, the players completed the questionnaire in September 2014 and/or 2015, which means that, for the 151 players who participated in both 2014-2015 and 2015-2016, a new baseline questionnaire was collected during the pre-season in 2015.

3.1.2.2 Baseline clinical test protocol

At baseline, all included players were measured according to the KHAST pre-season test protocol (107). This protocol included several measurements of shoulder strength, mobility and JPS as well as scapular kinesis, neck control, and trunk rotational mobility (107). Before preforming the test protocol, the players performed a standardised 8-minute warm-up programme for the shoulders consisting of 2×10 repetitions of abduction, flexion, and internal and external rotations for both shoulders with rubber tubes.

The tests were conducted at each school's sports facilities. The tests were performed at six test stations with one or two testers at each station, depending on the test to be performed. Each test were performed by the same tester or pair of tester during the baseline data collection except for shoulder ROM and JPS where two of the testers were replaced for the baseline data collection during the second season. All of the testers were well experienced with their tests and prior to the data collection started; every tester did practice runs of the entire test battery.

Shoulder strength

Shoulder strength was measured with a HHD (MicroFet2, Hoggan Health Industries Inc. West Jordan, UT, USA) Isometric external and internal rotation shoulder strength and eccentric external rotation shoulder strength were measured in both shoulders in a seated position with the arm in the frontal plane in 90° abduction (112, 113). Isometric abduction strength was measured in a standing position with the arm in 30° abduction in the scapular plane (40). Each test was performed twice.

Shoulder mobility

Passive glenohumeral rotational ROM was measured in both shoulders using a goniometer. The player was in a supine position with the shoulder in 90° abduction and elbow flexed to 90° (112). One tester fixed the scapula with one hand and performed a passive internal rotation of the humerus until movement of scapula was felt with the other hand. In this position, a second tester measured internal rotation ROM using a digital inclinometer. Passive external rotation of the humerus was measured in the same way. Two tests were performed in each shoulder in each direction.

Shoulder joint position sense

We measured shoulder JPS in the dominant shoulder with the player blindfolded and supine with the arm in the same starting position as for measuring ROM (112) The tester externally rotated the arm to a position of 75% of maximum external rotation (degrees of rotation were measured using a digital inclinometer). This position was called the target angle and the player was instructed to hold that position without support from the tester for three seconds, before the tester passively returned the arm to the starting position. The player was then instructed to actively rotate the arm back to the target angle. The tester measured the angle, and recorded the difference from the target angle. The test was performed three times and the average error was defined as the JPS error. In this study JPS was measured in external rotation with a target angle of 75% of the maximum external rotation because in the pilot study, many players reported shoulder pain or soreness when they actively externally rotated their shoulder to 90% of their maximum external rotation.

Scapular kinesis

Scapular dyskinesia was measured in both shoulders during active glenohumeral abduction and flexion in a standing position. A headlight was used to standardise the light setting for each test environment. The test was video recorded from a posterior view (standardised distance of 3 metres). Each player performed two repetitions of maximum shoulder abduction, and two repetitions of maximum shoulder flexion in random order with weights (one-kilogram dumbbell for females and two-kilogram for males). One tester later observed all videos and judged scapular dyskinesia as present or absent (114). Separate judgments of scapular dyskinesia were made for abduction and flexion.

Further clinical tests

In addition to the exposures analysed in this thesis, the players included in KHAST also performed a test for neck control and trunk mobility and shoulder instability (107). However, none of these data were used for the studies in this thesis.

Moreover, to study if the shoulder, trunk or neck function changes from baseline during the season, a convenient sample of three of the ten schools was regularly measured with the KHAST baseline test protocol about every second month during one or two of the competitive seasons. However, data from these repeated measurements were not used in this thesis.

3.1.2.3 Follow-up: injury registration and monitoring of handball training/matches

The players were monitored for shoulder injuries (traumatic and non-traumatic) and exposure time in handball matches and training sessions on a weekly basis with web-based questionnaires during the competitive season (September 2014 to April 2015 and September 2015 to April 2016).

The weekly questionnaires were based on the Swedish version of the OSTRC overuse injury questionnaire (110). The OSTRC overuse injury questionnaire includes four questions concerning the consequences of problems in the shoulder, with 4-5 answer alternatives of which each answer equals a specific score. For the purpose of this thesis, one answer option to the first question was added ("Could not participate/Reduced participation due to reason other than shoulder problems"). This was done to minimise any uncertainties for players who could not fully participate due to reasons other than shoulder problems (Appendix B). The survey software prohibited submissions of incomplete reports.

The players received an email with a link to the online weekly questionnaire each Sunday during the follow-up period. The players were encouraged to fill in the weekly report during school hours. For players who did no respond an automatically reminder was sent by e-mail the day after and by a mobile phone text message reminder using SMS three days after the initial email. For players who did not respond to this SMS within two days, a research assistant contacted them over the telephone and asked for their response.

3.1.3 Ethical considerations

The Regional Ethics Review Board of the Karolinska Institutet, Stockholm, Sweden, approved the study (2013/1722-31/4). All participating players, and legal guardians if the player was underage, gave written informed consent when entering the study.

3.1.3.1 Participation on a voluntary basis

Participation was voluntary and the participant could leave the study at any time without giving any specific reason. The school coaches were not aware of which of the students in his/her class were included or dropped out, or if they had answered the weekly reports or not. Moreover, the school coaches did not have access to any player's individual data.

3.1.3.2 Underaged participants

To give informed consent to participate in a study, the participants need to understand everything in the study information. This may be trickier with a younger population. To address this concern in this study, prior to the study start we had several meetings with groups consisting of both adolescent players and coaches where we went through the study information, questionnaires and test protocol and discussed any questions. Further, in this study, all underage respondents (under 18 years old) had to have the informed consent signed by both legal guardians.

3.1.3.3 Interventions

There is always the risk that the tests that the participants perform in a study could potentially harm the participant, for instance the maximum shoulder strength testing. In this case we judged that the test protocol that the players performed would not be more stressful to their shoulders than the handball they participated in on a daily basis. Additionally, if the player had any shoulder pain on the test day, we did not perform the maximum strength test for that shoulder, this in order to minimise the risk of increasing the player's pain.

Furthermore, there is also a question regarding how much and how many times it is appropriate to remind a person to answer the weekly reports. In the study, reminders were sent out by e-mail and, after three days, a mobile SMS message was also sent. If players also failed to respond to this SMS within the days, a research assistant contacted them over the telephone and asked for their response.

3.2 Material and methods in Study I-III

3.2.1 Prevalence of shoulder problems and pain (Study I)

3.2.1.1 Study population

All of the 471 male and female players from KHAST were included in Study I (Figure 2). For those who participated in both the 2014-2015 and 2015-2016 seasons, only data from the first season were used for the report of prevalence. Characteristics of the study population are presented in Table 4.

Table 4. Characteristics of the study population in study I.

	Females n=256 (54%)	**Males n=215 (46%)**
Age year, mean ±SD	16.4 ±0.8	16.4 ±0.9
Height cm, mean ±SD*	170.0 ±9.2	183.7 ±6.7
Weight kg, mean ±SD*	68.8 ±8.6	79.5 ±11.1
BMI, mean ±SD*	24.2 ±8.5	23.5 ±2.8
Years of playing handball, mean ±SD	9.2 ±2.1	9.0 ±2.3
School grade		
1st year students, n (%)	148 (58)	125 (58)
2nd year students, n (%)	69 (27)	59 (27)
3rd year students, n (%)	39 (15)	31 (15)
Playing position		
Goalkeepers, n (%)	35 (14)	37 (17)
Wing players, n (%)	45 (18)	50 (23)
Line players, n (%)	39 (15)	24 (11)
Backcourt players, n (%)	137 (53)	104 (49)
Level		
National level, n (%)	64 (25)	55 (26)
Regional level, n (%)	192 (75)	160 (74)

BMI body mass index, SD standard deviation
* Based on players who were available on the screening days (n=452)

3.2.1.2 Definition of shoulder problems and pain

Two types of shoulder problems were defined based on the information from the baseline and weekly follow-up questionnaires; any shoulder problems and substantial shoulder problems. If a player reported anything but the minimum value in any of the four questions in the modified Swedish OSTRC overuse injury questionnaire (Appendix B) this was defined as any shoulder problem.

For substantial shoulder problems, the original definition by Clarsen et al. was used; "Players who reported (shoulder) problems leading to moderate or severe reductions in training volume, or moderate or severe reductions in sports performance, or complete inability to participate in sport" (40). Consequently, players who selected options 3, 4 or 5 in questions 2 and/or 3 in the questionnaire were categorised as having substantial shoulder problems (Appendix B).

Wing and line players were categorised together as 6-m players for comparison of prevalence between playing positions. When comparing prevalence between different playing levels, the players were dichotomised to national level, defined as players who played for an adolescent national team or were summoned to a national camp during the preceding season, and regional level, defined as players who had not been summoned to a national camp during the preceding season i.e. only playing for their club teams.

3.2.1.3 Operational and Statistical methods

Descriptive data about player characteristics are presented as numbers and mean values with standard deviation (SD) or proportions with 95% confidence interval (CI). Four types of prevalence measures were calculated for this study and they are presented in Table 5.

Any differences in prevalence of shoulder problems and pain between sex, school grade, playing position, and playing level were estimated by calculating a prevalence ratio (PR) with 95% CI. PR was calculated by using generalised linear models with a binomial link function, including all factors (sex, school grade playing position and playing level) in each model. A sample size was calculated based on previous reported prevalence of shoulder problems and pain from adult elite handball players (40, 48), with a power of 80%, a significance level of 5% and an estimated drop-out rate of 10%. The sample size calculation showed that approximately 400 players were required to describe the prevalence and PR with a follow-up period of one competitive season.

Table 5. Prevalence measures, definitions and calculations in Study I.

Prevalence measures	Definition	Data collection	Numerator/denominator
Season prevalence of any shoulder problems and substantial shoulder problems (preceding season)	Any shoulder problems or substantial shoulder problems during the preceding season	Data collected retrospectively from baseline questionnaire	Numbers of players who reported having any shoulder problem and substantial shoulder problems, respectively, at some point during the preceding season divided by the total numbers of players in the cohort.
Weekly prevalence of any and substantial problems	Any shoulder problems or substantial shoulder problems during the preceding week during the follow-up season	Data collected prospectively via weekly reports throughout the follow-up period	Number of players who reported having any shoulder problem and substantial problems, respectively, at each week during the season, divided by the number of reports for that week
Season prevalence of any shoulder problems and substantial shoulder problems (follow-up season)	Any shoulder problems or substantial shoulder problems during the follow-up season	Data collected prospectively via weekly reports throughout the follow-up period	Numbers of players who reported having any shoulder problem and substantial shoulder problems, respectively, at some point during the follow-up season divided by the total numbers of players in the cohort.
Lifetime prevalence of shoulder pain	Any shoulder pain during handball participation at some point during the handball carrier	Data collected retrospectively from baseline questionnaire	Number of players who reported having had any previous shoulder pain during handball participation divided by the total numbers of players in the cohort

To assess any potential differences in sex, school grade, playing position and playing level, height, weight, Body Mass Index (BMI) (weight (kg)/(height (m))^2, and years of playing handball between those responding to less than 50% of the weekly reports and those responding to 50% or more unpaired t-test and chi-square test were used. For all statistical analyses STATA software (STATA/ICIC 14.1, StataCorp, Texas, USA) was used and the level of significance was set at 0.05.

3.2.2 Shoulder strength differences between sex and playing positions (Study II)

3.2.2.1 Study population

For this study, out of the 471 eligible participants in KHAST, only those who attended at the test day without shoulder pain and who could perform the shoulder strength tests in both arms were included. This resulted in a total of 341 players (176 females and 165 males) (Figure 3). Characteristics of the study population are presented in Table 6.

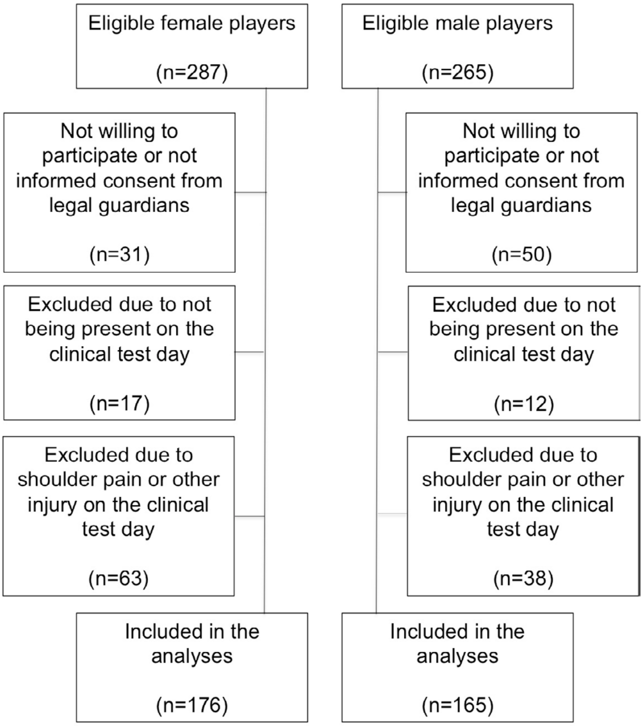

Figure 3. *The flow of the study participants in Study II.*

Table 6. Characteristics of the study population in Study II.

	Females				Males			
	n (%)	**Age Mean ±SD**	**Height cm Mean ±SD**	**Weight kg Mean ±SD**	**n (%)**	**Age Mean ±SD**	**Height cm Mean ±SD**	**Weight kg Mean ±SD**
Total population	176	16.3 ±0.8	169.5 ±10.0	68.4 ±8.8	165	16.4 ±0.8	183.9 ±6.8	79.6 ±11.8
Playing position								
Goalkeeper	26 (15)	16.3 ±0.7	170.3 ±5.1	70.7 ±10.0	25 (15)	16.5 ±0.8	182.8 ±3.8	82.6 ±11.9
Wing	35 (20)	16.4 ±0.8	166.8 ±5.7	63.1 ±6.6	40 (24)	16.4 ±0.9	181.6 ±7.3	73.4 ±11.1
Line	30 (17)	16.5 ±0.8	172.7 ±5.6	72.7 ±7.7	20 (12)	16.3 ±0.7	184.1 ±5.5	88.3 ±8.9
Backcourt	85 (48)	16.2 ±0.8	170.4 ±6.0	68.3 ±8.6	80 (49)	16.3 ±0.8	185.0 ±7.6	79.6 ±9.6
School grade								
1^{st}	111 (63)	15.8 ±0.4	170.3 ±5.9	68.2 ±9.3	99 (63)	15.8 ±0.4	183.2 ±6.9	78.3 ±11.1
2^{nd} and 3^{rd}	65 (37)	17.1 ±0.6	169.7 ±6.1	68.6 ±7.9	66 (37)	17.1 ±0.6	184.5 ±6.9	81.5 ±10.9
Playing level								
Regional	131 (74)	16.4 ±0.8	169.6 ±6.0	68.1 ±8.6	124 (74)	16.4 ±0.9	183. 2 ±6.7	78.8 ±11.1
National	45 (26)	16.0 ±0.6	171.5 ±5.9	69.2 ±9.5	41 (26)	16.3 ±0.7	185.4 ±7.5	81.9 ±10.9

SD standard deviation

3.2.2.2 *Statistical methods*

Descriptive data about player characteristics are presented as numbers and mean values with standard deviation (SD) or proportions with 95% confidence interval (95% CI).

For Study II, strength values from KHAST baseline testing were used. Relative reliability of the shoulder tests was assessed by calculating the intra-class correlation coefficient (ICC) with the corresponding 95% CI. The two performances for each strength measurement were used, and $ICC_{3,1}$ (two-way random model absolute agreement) was calculated. ICC was interpreted as: ≥90 = excellent, 0.80-0.89 = good, 0.70-0.79 moderate and <0.70 = low. Standard error of measurement (SEM) for each ICC estimate was calculated as SD × √1-ICC. The SEM was used for calculating the MDC_{95}, as 1.96*SEM* √2 (112).

Strength values are presented as mean Newton (N) as well as mean values normalised by bodyweight (N/kg), with SD. Strength ratios for isometric external rotation/isometric internal rotation strength and eccentric external rotation/isometric internal rotation strength are presented as mean values with corresponding 95% CI. Potential differences in strength values between male and female players, and sex-specific differences in playing positions, school grades and playing levels, were calculated using unpaired and paired t-tests. STATA software (STATA/ICIC 14.1, StataCorp, Texas, USA) was used for all statistical analyses and the level of significance was set at 0.05.

3.2.3 Risk factors for shoulder injuries (Study III)

3.2.3.1 *Study population*

For Study III, a shoulder-injury-free cohort was defined from the KHAST cohort, i.e. players who did not report a score of at least 40 on the OSTRC overuse injury questionnaire (described earlier) in the dominant shoulder for the past two months, and had no problems in performing the baseline measures were included, resulting in 344 players (452 player seasons, 50% females) (Figure 4). Characteristics of the study population are presented in Table 7.

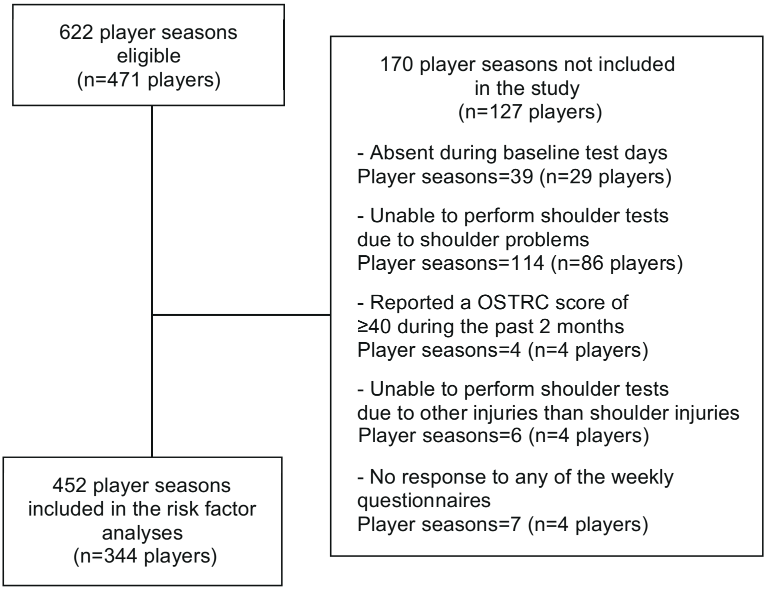

Figure 4. *The flow of the of study participants in Study III (© Journal of Orthopaedic & Sports Physical Therapy).*

Table 7. Characteristics of the study population in study III.

	Females player seasons = 226 (n=180)	**Males player seasons = 226 (n=164)**
Age year, mean ±SD	16.5 ± 0.9	16.6 ± 0.8
Height cm, mean ±SD	169.6 ± 9.3	183.9 ± 6.8
Weight kg, mean ±SD	69.3 ± 8.9	80.1 ± 10.6
Years of playing handball, mean ± SD	9.4 ± 2.1	9.3 ± 2.3
Playing position		
Goalkeepers, player seasons (%)	37 (16)	41 (18)
Wing players, player seasons (%)	41 (18)	51 (23)
Line players, player seasons (%)	41 (18)	29 (13)
Back players, player seasons (%)	107 (48)	105 (46)
School grade		
1st grade, player seasons (%)	115 (51)	100 (44)
2nd grade, player seasons (%)	74 (33)	83 (37)
3rd grade, player seasons (%)	37 (16)	43 (19)
History of shoulder pain, n (%)	77 (34)	66 (29)
Playing level		
Regional, player seasons (%)	169 (75)	175 (77)
National, player seasons (%)	57 (25)	52 (23)

SD standard deviation.

3.2.3.2 Exposures

Exposures were based on the baseline measurement from KHAST. For all exposures the values from the dominant shoulder was used, except for ROM were measurement from both arms was used to define side-to-side difference. The exposures included shoulder strength, shoulder ROM, shoulder JPS, and scapular dyskinesia, and are presented in Table 8.

Table 8. Categorisation of the exposures analysed as potential risk factors for shoulder injuries in the dominant arm in Study III.

Strength normalised by body weight - Newton/kg
Isometric external rotation
Isometric internal rotation
Eccentric external rotation
Isometric abduction
Ratio between isometric external rotation and isometric internal rotation <0.75
Ratio between eccentric external rotation and isometric internal rotation <0.75
Range of motion
Internal rotation
External rotation
Total range of motion (sum score of internal rotation + external rotation)
Difference in total range of motion (dominant vs. non-dominant shoulder)
Scapular dyskinesia
Scapular dyskinesia during flexion
Scapular dyskinesia during abduction
Joint position sense
Mean error measurement from TA

TA target angle.

Strength, range of motion and joint position sense was dichotomised on median values. Scapula dyskinesia was dichotomised as yes or no.

3.2.3.3 Confounding

A priori, we chose a set of potential confounders based on the literature of potential risk factors. The potential confounders were measured at baseline and included playing position, school grade, school and playing level. In the end, the number of events limited the ability to adjust for several confounders in the same model, and therefore only playing position was included in the adjusted model.

3.2.3.4 Outcome measures

The primary outcome was first incidence of shoulder injury in the dominant arm, regardless of being reported as a traumatic or overuse injury. Each answer in the OSTRC overuse injury questionnaire corresponds to a score, with a sum score between 0 and 100 for the total questionnaire (64). Shoulder injury was defined as reporting a score of 40 or more from the dominant shoulder at some point during the season.

3.2.3.5 Reliability

Every measurement was performed either twice (strength and ROM) or three times (JPS) at baseline and these results were used to calculate the intra-rater reliability of each measure and for each tester. Moreover, we used the data from the first 43 players assessed at baseline to analyse the intra-agreement of scapula dyskinesia.

3.2.3.6 Statistical methods

We calculated the ICC with the corresponding 95% CI to assess the relative reliability of the shoulder tests. The two performances for each strength and ROM measurement were used for intra-reliability, and $ICC_{3,1}$ (two-way random model absolute agreement) was calculated. For the measurement JPS, three performances were recorded, but only the last two performances were used to calculate the ICC. The SEM was calculated as SD × √1-ICC. We calculated the Cohen's kappa value with corresponding 95% CI and percentage of agreement to assess the reliability of the scapular dyskinesia classification.

We calculated injury incidence as the numbers of injuries divided by 1,000 hours of handball (matches and training sessions). For each exposure, we built a multivariable Cox proportional hazard model to calculate a hazard rate ratio (HRR) and 95% CI for the association between the exposures and the event of the first injury. Time at risk was set as the number of hours of matches and training sessions on the handball court between baseline and the first injury to the dominant shoulder. Players who reported a shoulder injury or chose to leave the study were censored. Players who reported other reasons for not fully participating in handball (e.g. school breaks, other school commitments or other injuries or illnesses, etc.) were not censored as time at risk was based on number of hours exposed to handball and not on calendar time. Players were excluded from all analyses if they did not respond to any weekly reports.

The statistical modelling strategy included two steps. In the first step, we performed crude analyses for each exposure, and, in the second step, we adjusted for playing position. For each model, the proportional hazard assumption (e.g. that the multiplicative effect of the hazard function is constant over time) was achieved.

4 RESULTS

4.1 Prevalence of shoulder problems and pain (Study I)

In total, 12,931 weekly reports were collected during the follow-up season, with an average every-week response of 93% (range 87-98%). Seventy-three percent of the players responded to all of the weekly questionnaires.

4.1.1 Week prevalence of shoulder problems

The average weekly prevalence of any shoulder problems was 25% (95% CI 23-27) and for substantial shoulder problems 6% (95% CI 5-7).

4.1.2 Season prevalence of shoulder problems during the preceding season

The season prevalence of any shoulder problems during the preceding season was 28% (95% CI 24-32) and for substantial shoulder problems 13% (95% CI 10-16). Female players and backcourt players had a higher prevalence of any and substantial shoulder problems during the preceding season. The prevalence of substantial shoulder problems during the preceding season was higher in 2nd and 3rd grade students compared with 1st grade students as well (Table 9).

Table 9. Season prevalence and prevalence ratios of any shoulder problems and substantial shoulder problems during the proceeding season.

	No. of players	Any shoulder problems, n (%)	PR* (95% CI)	Substantial shoulder problems, n (%)	PR* (95% CI)
Total	471	133 (28)		60 (13)	
Sex					
Males	215	50 (23)	1.0	22 (10)	1.0
Females	256	83 (32)	1.36 (1.02-1.83)	38 (15)	1.36 (0.84-2.19)
School grade					
1st year students	273	70 (26)	1.0	21 (8)	1.0
2nd and 3rd year students	198	63 (32)	1.22 (0.92-1.62)	39 (20)	2.54 (1.55-4.17)
Playing position					
6-meter players**	158	35 (22)	1.0	19 (12)	1.0
Backcourt players	241	85 (35)	1.59 (1.14-2.22)	38 (16)	1.33 (0.80-2.19)
Goalkeepers	72	13 (18)	0.82 (0.47-1.46)	3 (4)	0.36 (0.11-1.16)
Playing level					
Regional	352	100 (28)	1.0	45 (13)	1.0
National	119	33 (28)	0.98 (0.71-1.36)	15 (13)	1.04 (0.61-1.77)

CI confidence interval, PR prevalence ratio.
* Adjusted for each other; sex, playing position, school grade and playing level.
** 6-meter players include wing and line players.

4.1.3 Season prevalence during the follow-up season

The season prevalence of any shoulder problems and substantial shoulder problems during the follow-up season was 44% (95% CI 40-48) and 23% (95% CI 20-27), respectively. Both any and substantial shoulder problems were more common in female players and backcourt players (Table 10).

Table 10. Prevalence and prevalence ratios of any shoulder problems and substantial shoulder problems at some point during the follow-up season.

	No. of players	Any shoulder problems, n (%)	PR* (95% CI)	Substantial shoulder problems, n (%)	PR* (95% CI)
Total	471	207 (44)		110 (23)	
Sex					
Males	215	83 (39)	1.0	40 (19)	1.0
Females	256	124 (48)	1.25 (1.02-1.54)	70 (27)	1.46 (1.04-2.06)
School grade					
1st year students	273	116 (42)	1.0	59 (22)	1.0
2nd and 3rd year students	198	91 (46)	1.11 (0.91-1.35)	51 (26)	1.21 (0.88-1.67)
Playing position					
6-meter players**	158	62 (40)	1.0	29 (18)	1.0
Backcourt players	241	124 (51)	1.32 (1.05-1.66)	70 (29)	1.58 (1.08-2.32)
Goalkeepers	72	21 (29)	0.75 (0.50-1.12)	11 (15)	0.84 (0.45-1.59)
Playing level					
Regional	352	155 (44)	1.0	80 (23)	1.0
National	119	52 (44)	0.99 (0.79-1.24)	30 (25)	1.09 (0.76-1.56)

CI confidence interval, PR prevalence ratio
*Adjusted for each other; sex, playing position, school grade and playing level
**6-meter players include wing and line players

4.1.4 Lifetime prevalence of shoulder pain

Forty-one percent of the players reported having had shoulder pain at some point during their life (95% CI 36-45). The lifetime prevalence was higher among female players compared with males; 46% versus 35% (PR 1.26, 95% 1.01-1.57). Moreover, the prevalence was higher among backcourt players compared with 6-m players; 51% versus 32% (PR 1.57, 95% CI 1.22-2.03). It was also higher among 2nd and 3rd grade students compared with 1st grade students; 45% versus 37% (PR 1.22, 95% CI 0.99-1.50). There were no differences between players competing at a regional level compared with players at a national level; 43% versus 41% (PR 1.07, 95% CI 0.84-1.35).

4.1.5 Duration of the shoulder problems

Of those who reported substantial shoulder problems during the follow-up season, 48% reported complete inability to participate due to shoulder problems. In total, 75% (95% CI 69-81) of those with any shoulder problems during the follow-up reported such problems for at least three consecutive weeks during the season. Similarly, 43% (95% CI 39-48) of those with substantial shoulder problems during the follow-up reported such problems for at least three consecutive weeks during the season. Moreover, of those with shoulder problems and substantial shoulder problems at some point during the preceding season, 77% (95% CI 66-85) and 67% (95% CI 58-75), respectively, also reported such problems at least once during the follow-up season.

4.1.6 Comparison between players with low and high response rates

No significant differences were found in sex, school grade, playing position, and playing level or in height, weight, BMI, and years of playing handball between the players responding to less than 50% of the weekly questionnaires (n = 33) and players responding 50% or more (n = 438).

4.2 Shoulder strength differences between sexes and playing positions (Study II)

For Study II, players from the KHAST cohort who were not present at the test day (n=29), could not perform the shoulder tests due to shoulder pain (n=97) or injuries in other part of their bodies (n=4) were excluded. This resulted in a study sample of 341 players (176 females), as shown in Figure 3.

4.2.1 Reliability

The ICC of the strength tests ranged from 0.90 to 0.95 in male players and from 0.88 to 0.92 in female players.

4.2.2 Reference values

Mean values for shoulder strength, both absolute strength and normalised by bodyweight (N/kg) and strength ratios stratified by playing position, grade and playing level in female and male adolescent elite handball players are presented in Tables 11 and 12.

Table 11. Mean and SD (±) for shoulder strength values normalised by bodyweight (N/kg) and strength ratios (95% CI) stratified by playing position, grade and playing level in male adolescent elite handball players.

	n (%)		IER Mean ±SD D	IER ND	IIR Mean ±SD D	IIR ND	EER Mean ±SD D	EER ND
Total population	165	N	124±23[a*]	114±21	179±38[a*]	164± 37	155± 30[a*]	149± 27
		N/kg	1.6±0.2[a*]	1.5±0.3	2.3±0.5[a*]	2.1± 0.4	2.0± 0.4[a*]	1.9± 0.3
Playing position								
Goalkeeper	25 (15)	N	119±21	114±20	167±29	147±33	153±25	149±27
		N/kg	1.5±0.3	1.4±0.3	2.1±0.4	1.8±0.4	1.9±0.3	1.8±0.4
Wing	40 (24)	N	116±23	108±21	168±36	159±34	153±31	149±28
		N/kg	1.6±0.3	1.5±0.3[e*]	2.3±0.5	2.2± 0.5[f*]	2.1±0.4[c,e,f**]	2.1±0.4[c,e,f,*]
Line	20 (12)	N	128±14[e**]	116±16	200±33[e,g*]	186±38 [e**,g*]	166±29	150±23
		N/kg	1.5±0.2	1.3±0.2	2.3±0.4	2.1±0.5[g**]	1.9±0.3	1.7±0.2
Backcourt	80 (49)	N	128±24 [c**]	118±22 [c**]	183±40 [c**]	167±38[b**]	153±31	148±28
		N/kg	1.6±0.3	1.5±0.3[d**]	2.3±0.5	2.1±0.4[c*]	1.9±0.4	1.9±0.3[d**]
School grade								
1st	99 (63)	N	120±22	112±20	177±38	159±36	149±29	142±25
		N/kg	1.6±0.3	1.4±0.3	2.3±0.5	2.1±0.5	1.9±0.4	1.8±0.3
2nd and 3rd	66 (37)	N	129±23[h**]	119±22[h**]	183±39	171±39[h**]	163±29[h*]	159±28[h*]
		N/kg	1.6±0.3	1.48±0.30	2.3±0.5	2.1±0.4	2.0±0.4	2.0±0.3[h*]
Level								
Regional	124 (74)	N	121±22	113±21	177±37	161±36	152±29	149±28
		N/kg	1.6±0.3	1.5±0.3	2.3±0.4	2.1±0.4	2.0±0.4	1.9±0.3
National	41 (26)	N	132±22[i**]	118±20	187±42	174±41	162±32	152±25
		N/kg	1.6±0.3	1.5±0.3	2.3±0.5	2.1±0.5	2.0±0.4	1.9±0.3

CI confidence interval, D dominant, IER isometric external rotation, IIR isometric internal rotation, EER eccentric external rotation, IABD isometric abduction, kg kilogram, N Newton ND non-dominant,
SD standard deviation
* p<0.05
** p<0.005
[a] Significant difference between dominant and non-dominant arm, [b] Significant differences between backcourt players and goalkeepers, [c] Significant differences between backcourt players and wing players, [d] Significant differences between backcourt players and line players, [e] Significant differences between wing players and line players, [f] Significant differences between wing players and goalkeepers, [g] Significant differences between line players and goalkeepers, [h] Significant difference between 1st grade and 2nd and 3rd grade student, [i] Significant differences between national and regional.

Table 11. Continued.

	n (%)		IABD Mean ±SD D	IABD Mean ±SD ND	Total strength Mean ±SD D	Total strength Mean ±SD ND	Ratios Mean ±SD, (95% CI) IER:IIR D	IER:IIR ND	EER:IIR D	EER:IIR ND
Total population	165	N	123±23[a*]	118±21	581±91[a*]	546±84	0.71±0.13	0.72±0.15	0.89±0.20[a*]	0.96±0.18
		N/kg	1.6±0.3[a*]	1.5±0.2	7.4±1.1[a*]	6.9±1.0	(0.69-0.73)	(0.70-0.74)	(0.91-0.97)	(0.86-0.92)
Playing position										
Goalkeeper	25 (15)	N	115±23	114±21	554±81	525±73	0.72±0.12	0.80±0.17[b,f**,g*]	0.93±0.14	1.05±0.23[b**,g*]
		N/kg	1.4±0.2	1.4±0.2	6.8±1.0	6.4±0.9	(0.67-0.77)	(0.73-0.87)	(0.87-0.99)	(0.96-1.14)
Wing	40 (24)	N	118±24	112±19	555±89	529±85	0.71±0.12	0.70±0.14	0.94±0.25[c**]	0.96±0.20[e**]
		N/kg	1.6±0.3[f*]	1.5±0.3	7.6±1.2[f**]	7.3±1.1[e**,f*]	(0.67-0.75)	(0.66-0.74)	(0.86-1.02)	(0.90-1.03)
Line	20 (12)	N	136±23[e**,g*]	125±18[e**]	631±71[e, g*]	575±72[e*,g**]	0.66±0.13	0.65±0.12	0.84±0.20	0.84±0.16
		N/kg	1.5±0.3	1.4±0.2	7.2±1.0	6.6±0.9	(0.60-0.72)	(0.59-0.71)	(0.75-0.93)	(0.77-0.91)
Backcourt	80 (49)	N	125±22[c*]	120±[21c**]	590±95	553±87	0.71±0.13	0.72±0.14[e*]	0.86±0.17	0.92±0.21
		N/kg	1.6±0.3[b*]	1.5±0.2[b,d**]	7.4±1.0[b**]	7.0±0.8[b*]	(0.68-0.74)	(0.69-0.75)	(0.82-0.90)	(0.87-0.97)
School grade										
1st	99 (63)	N	120±23	114±20	567±91	538±84	0.71±0.13	0.69±0.13	0.86±0.18	0.93±0.21
		N/kg	1.6±0.3	1.5±0.3	7.3±1.1	6.8±1.0	(0.68-0.74)	(0.66-0.72)	(0.82-0.90)	(0.89-0.97)
2nd and 3rd	66 (37)	N	128±24[h**]	123±21[h*]	603±90[h**]	567±82[h*]	0.71±0.13	0.72±0.13	0.92±0.22	0.96±0.21
		N/kg	1.6±0.3	1.5±0.2	7.4±1.0	7.1±0.9	(0.68-0.74)	(0.69-0.75)	(0.87-0.97)	(0.91-1.01)
Level										
Regional	124 (74)	N	121±23	116±20	571±89	538±84	0.70±0.12	0.72±0.14	0.88±0.20	0.95±0.20
		N/kg	1.6±0.3	1.5±0.2	7.3±1.0	6.9±1.0	(0.68-0.72)	(0.70-0.74)	(0.84-0.92)	(0.91-0.99)
National	41 (26)	N	129±24	124±21[i**]	610±95[i**]	568±82[i**]	0.73±0.15	0.71±0.16	0.89±0.20	0.92±0.24
		N/kg	1.6±0.3	1.5±0.3	7.5±1.2	7.0±1.0	(0.68-0.78)	(0.70-0.76)	(0.83-0.95)	(0.84-1.00)

CI confidence interval, D dominant, IER isometric external rotation, IIR isometric internal rotation, EER eccentric external rotation, IABD isometric abduction, kg kilogram, N Newton ND non-dominant,
SD standard deviation
* $p<0.05$
** $p<0.005$
[a] Significant difference between dominant and non-dominant arm, [b] Significant differences between backcourt players and goalkeepers, [c] Significant differences between backcourt players and wing players, [d] Significant differences between backcourt players and line players, [e] Significant differences between wing players and line players, [f] Significant differences between wing players and goalkeepers, [g] Significant differences between line players and goalkeepers, [h] Significant difference between 1st grade and 2nd and 3rd grade student, [i] Significant differences between national and regional.

Table 12. Mean and SD (±) for shoulder strength values normalised by bodyweight (N/kg) and strength ratios (95% CI) stratified by playing position, grade and playing level in female adolescent elite handball players.

			IER Mean±SD		IIR Mean±SD		EER Mean±SD	
	n (%)		D	ND	D	ND	D	ND
Total population	176	N	97±17^{a*}	90±16	128±28^{a*}	114±24	120±30^{a*}	115±18
		N/kg	1.4± 0.3^{a*}	1.3±0.3	1.9±0.5^{a*}	1.7±0.4	1.8±0.3^{a*}	1.7±0.3
Playing position								
Goalkeeper	26 (15)	N	95±14	88±15	127±24	112±28	120±19	112±16
		N/kg	1.4±0.3	1.3±0.3	1.8±0.4	1.6±0.4	1.7±0.3	1.6±0.3
Wing	35 (20)	N	94±18	87±14	123±27	110±21	118±20	116±19
		N/kg	1.5±0.3^{b*}	1.4±0.3^{b*}	2.0±0.5^{b*}	1.8±0.4^{b*}	1.9±0.4^{b,c**}	1.9±0.3^{b,c,d*}
Line	30 (17)	N	97±17	90±18	127±33	106±23	122±21	114±19
		N/kg	1.3±0.2	1.2±0.2	1.7±0.4	1.5±0.4	1.7±0.3	1.6±0.3
Backcourt	85 (48)	N	99±17	92±16	130±28	119±24^{d**}	120±18	116±18
		N/kg	1.5±0.3^{e*}	1.4±0.3^{e*}	1.9±0.4^{e**}	1.8±0.4$^{e*,\,f**}$	1.8±0.3	1.7±0.3
School grade								
1st	111 (63)	N	97±18	91±16	127±31	114±25	120±19	115±19
		N/kg	1.4±0.3	1.4±0.3	1.9±0.5	1.7±0.4	1.8±0.3	1.7±0.3
2nd and 3rd	65 (37)	N	97±14	88±16	129±24	114±22	120±18	115±17
		N/kg	1.4±0.3	1.3±0.3	1.9±0.4	1.7±0.4	1.8±0.3	1.7±0.2
Playing level								
Regional	131 (74)	N	97±17	89±16	126±29	113±25	118±18	114±18
		N/kg	1.4±0.3	1.3±0.3	1.9±0.5	1.7±0.4	1.8±0.3	1.7±0.3
National	45 (26)	N	97±14	92±14	132±25	115±23	125±19^{h*}	119±17
		N/kg	1.4±0.2	1.4±0.2	1.9±0.4	1.7±0.4	1.8±0.3	1.7±0.3

CI confidence interval, D dominant, IER isometric external rotation, IIR isometric internal rotation, EER eccentric external rotation, IABD isometric abduction, kg kilogram, N Newton ND non-dominant,
SD standard deviation
* $p<0.05$** $p<0.005$[a] Significant differences between dominant and non-dominant arm. [b] Significant differences between wing players and line players. [c] Significant differences between wing players and goalkeepers
[d] Significant differences between wing players and backcourt players. [e] Significant differences between backcourt players and line players. [f] Significant differences between backcourt players and goalkeepers
[h] Significant differences between national and regional players

Table 12. Continued.

			IABD Mean±SD		Total strength Mean±SD		Ratios Mean±SD, (95% CI)			
	n (%)		**D**	**ND**	**D**	**ND**	**IER:IIR D**	**IER:IIR ND**	**EER:IIR D**	**EER:IIRND**
Total population	176	N	90±15[a]*	87±17	435±60[a]*	406±56	0.78±0.17[a]*	0.82±0.18	0.98±0.23[a]*	1.05±0.24
		N/kg	1.3±0.2	1.3±0.3	6.4±1.0[a]*	6.0±0.9	(0.76-0.81)	(0.79-0.84)	(0.94-1.01)	(1.01-1.08)
Playing position										
Goalkeeper	26 (15)	N	87±14	83±18	429±57	395±59	0.77±0.14	0.82±0.20	0.97±0.18	1.04±0.19
		N/kg	1.2±0.2	1.2±0.3	6.2±1.0	5.7±1.0	(0.71-0.83)	(0.74-0.90)	(0.90-1.04)	(0.96-1.12)
Wing	35 (20)	N	91±15	87±13	427±52	401±49	0.80±0.25	0.81±0.16	1.01±0.30	1.08±0.24
		N/kg	1.5±0.3[b,c,d]*	1.4±0.3[b,c]*	6.8±1.0[b*,c**]	6.4±1.0[b*,c**]	(0.71-0.89)	(0.76-0.86)	(0.91-1.11)	(1.00-1.16)
Line	30 (17)	N	91±15	86±14	436±72	397±55	0.79±0.15	0.87±0.23[e]**	1.00±0.25	1.12±0.30[e]**
		N/kg	1.3±0.2	1.2±0.2	6.0±1.0	5.5±0.9	(0.73-0.85)	(0.78-0.96)	(0.91-1.09)	(1.01-1.23)
Backcourt	85 (48)	N	90±15	88±18	439±61	415±57	0.78±0.16	0.79±0.15	0.96±0.21	1.01±0.23
		N/kg	1.3±0.2[f]**	1.3±0.3	6.5±0.9[e]**	6.1±0.9[e*, f**]	(0.75-0.81)	(0.76-0.82)	(0.91-1.01)	(0.96-1.06)
School grade										
1st	111 (63)	N	88±16	86±18	433±64	407±60	0.79±0.20	0.83±0.17	0.99±0.25	1.05±0.23
		N/kg	1.3±0.2	1.3±0.3	6.4±1.0	6.0±1.0	(0.75-0.83)	(0.80-0.86)	(0.94-1.04)	(1.01-1.09)
2nd and 3rd	65 (37)	N	92±14	88±14	437±54	405±48	0.77±0.13	0.80±0.19	0.96±0.20	1.05±0.26
		N/kg	1.4±0.3	1.3±0.3	6.5±1.0	6.0±0.9	(0.74-0.80)	(0.75-0.85)	(0.91-1.01)	(1.00-1.11)
Playing level										
Regional	131 (74)	N	89±15	85±15	430±62	402±56	0.79±0.19	0.81±0.17	0.98±0.24	1.04±0.24
		N/kg	1.3±0.2	1.3±0.24	6.4±1.0	6.0±1.0	(0.76-0.82)	(0.78-0.84)	(0.94-1.02)	(1.00-1.08)
National	45 (26)	N	92±14	92±19[h]*	448±54	419±51	0.76±0.14	0.83±0.18	0.98±0.21	1.06±0.23
		N/kg	1.4±0.2	1.3±0.3	6.5±0.8	6.1±0.9	(0.72-0.80)	(0.78-0.88)	(0.92-1.04)	(0.99-1.13)

CI confidence interval, D dominant, IER isometric external rotation, IIR isometric internal rotation, EER eccentric external rotation, IABD isometric abduction, kg kilogram, N Newton ND non-dominant,
SD standard deviation
* $p<0.05$** $p<0.005$[a] Significant differences between dominant and non-dominant arm. [b] Significant differences between wing players and line players.
[c] Significant differences between wing players and goalkeepers
[d] Significant differences between wing players and backcourt players. [e] Significant differences between backcourt players and line players. [f] Significant differences between backcourt players and goalkeepers
[h] Significant differences between national and regional players

4.2.3 Shoulder strength in male players

In males, backcourt players and line players were in general significantly stronger compared with goalkeepers and wing players. However, backcourt and wing players were generally stronger than line players and goalkeepers when normalised by bodyweight. Male players were stronger in the dominant side compared with the non-dominant side in all shoulder positions tested ($p<0.0001$). Players in the 2nd and 3rd grades were in general stronger compared with those in the 1st grade, but no differences were seen when normalised by bodyweight. Male players competing at a national level were in general stronger compared to those at a regional level, but no differences were seen when normalised by bodyweight (Table 11).

4.2.4 Shoulder strength in female players

In females, there were no differences in absolute strength between the different playing positions, except that backcourt players were stronger than line players in IIR in the non-dominant arm. When normalised by bodyweight, however, wing players and backcourt players were in general stronger compared to line players and goalkeepers. As in male players, female players were stronger in the dominant arm compared to the non-dominant arm in all shoulder positions tested ($p<0.0005$). No differences were seen between the school grades regardless of normalisation by bodyweight or not. Players competing at the national level were stronger in EER in the dominant arm and in isometric abduction in the non-dominant arm compared with players at a regional level when normalised by bodyweight. No other differences were seen between national and regional level players (Table 12).

4.2.5 Differences in shoulder strength between males and females

Male players were stronger than female players in each test position in both arms, both in terms of absolute strength and when normalised by bodyweight ($p < 0.0001$). Mean differences in N and N/kg between males and females with corresponding 95% CI and p values are presented in Table 13.

Table 13. Mean values and SD (±) and differences in shoulder strength between female and male adolescent elite handball players (Study II).

Dominant shoulder	**Females n=176**	**Males n=165**	**Mean difference, (95%)**	**Mean difference percentage**	**P-value**
IER N IER N/kg	97 ±17 1.4 ± 0.3	124 ±23 1.6 ±0.2	27 (22-31) 0.2 (0.1-0.3)	28% 14%	<0.0001
IIR N IIR N/kg	128 ±28 1.9 ±0.5	179 ±38 2.3 ±0.5	51 (44-58) 0.4 (0.3-0.5)	40% 21%	<0.0001
EER N EER N/kg	120 ±30 1.8 ±0.3	155 ±30 2.0 ±0.4	35 (29-41) 0.2 (0.1-0.3)	29% 11%	<0.0001
IABD N IABD N/kg	90 ±15 1.3 ±0.2	123 ±23 1.6 ±0.3	33 (29-37) 0.3 (0.2-0.4)	37% 23%	<0.0001
Total strength N Total strength N/kg	435 ±60 6.4 ±1.0	581 ±91 7.4 ±1.1	146 (130-162) 1.0 (0.8-1.2)	34% 16%	<0.0001
IER:IIR (95% CI)	0.78 ±0.17 (0.76-0.81)	0.71 ±0.13 (0.69-0.73)	0.07 (0.04-0.10)	10%	<0.0001
EER:IIR (95% CI)	0.98 ±0.23 (0.94-1.01)	0.89 ±0.20 (0.91-0.97)	0.09 (0.04-0.14)	10%	0.0001
Non-dominant shoulder					
IER N IER N/kg	90 ±16 1.3±0.3	114 ±21 1.5 ±0.3	24 (10-28) 0.2 (0.1-0.3)	27% 15%	<0.0001
IIR N IIR N/kg	114 ±24 1.7 ±0.4	164 ±37 2.1 ±0.4	50 (43-57) 0.4 (0.3-0.5)	44% 24%	<0.0001
EER N EER N/kg	115 ±18 1.7 ±0.3	149 ±27 1.9 ±0.3	34 (29-39) 0.2 (0.1-0.3)	30% 12%	<0.0001
ABD N ABD N/kg	87 ±17 1.3 ±0.3	118 ±21 1.5 ±0.2	31 (27-35) 0.2 (0.1-0.3)	36% 15%	<0.0001
Total strength N Total strength N/kg	406 ±56 6.0 ±0.9	546 ±84 6.9 ±1.0	140 (125-155) 0.9 (0.7-1.1)	34% 15%	<0.0001
IER:IIR (95% CI)	0.82 ±0.18 (0.79-0.84)	0.72 ±0.15 (0.70-0.74)	0.10 (0.06-0.14)	14%	<0.0001
EER:IIR (95% CI)	1.05 ±0.24 (1.01-1.08)	0.96 ±0.18 (0.86-0.92)	0.09 (0.04-0.14)	9%	0.0001

CI confidence interval, IER isometric external rotation, IIR isometric internal rotation, EER eccentric external rotation, IABD isometric abduction, kg kilogram, N Newton, SD standard deviation.

4.3 Risk factors for shoulder injuries (Study III)

Of the 344 participants, 18 (4%) dropped out of the study, primarily due to leaving the handball-profiled secondary school.

The average weekly response rate during the follow-up period was 92% (95% CI 0.91-0.94), with 345 of 452 player seasons (76%) reporting complete data. Male players had a total time at risk of 31,416 hours while female players had 28,089 hours.

In total, 48 new shoulder injuries in the dominant arm were recorded (26 in female players and 22 in male players), 42 of them (88%) were reported as non-traumatic. In male players the incidence of shoulder injuries in the dominant arm was 0.70/1,000 hours (95% CI 0.53-0.84) and in female players 0.93/1,000 hours (95% CI 0.76-0.99).

4.3.1 Reliability

The ICC for the strength tests ranged from 0.83 to 0.96, for the ROM tests from 0.83 to 0.97 and for the JPS test from 0.68 to 0.95. Cohen's kappa values for scapula dyskinesia ranged from 0.85 to 0.92. The ICC, Cohen's kappa values and percentage of agreement are presented in Table 14.

Table 14. Intra-examiner reliability ($ICC_{3,1}$) with corresponding 95 % CI and SEM and Cohen's kappa with corresponding 95% CI for the assessment of strength, ROM, JPS and scapula dyskinesia.

	Test leaders during season one		**Test leaders during season two**	
Test	**ICC (95% CI)**	**SEM**	**ICC (95% CI)**	**SEM**
IER	0.91 (0.89-0.93)	6.96	na*	na*
IIR	0.96 (0.95-0.97)	8.47	na*	na*
EER	0.92 (0.91-0.93	8.24	na*	na*
IABD	0.92 (0.90-0.94	7.18	na*	na*
ER	0.97 (0.95-0.98)	2.03	0.83 (0.78-0.89)	4.25
IR	0.96 (0.94-0.96)	1.60	0.88 (0.85-0.90)	3.43
JPS	0.68 (0.60-0.75)	6.90	0.95 (0.93-0.96)	2.64
	Cohen's kappa (95% CI)	**% of agreement**	**Cohen's kappa (95% CI)**	**% of agreement**
Scapula dyskinesia abduction	0.92 (0.86-0.96)	97	na*	na*
Scapula dyskinesia flexion	0.85 (0.74-0.91)	93	na*	na*

ICC intra class correlation, IER isometric external rotation, IIR isometric internal rotation, EER eccentric external rotation, IABD isometric abduction strength, ER external rotation, IR internal rotation, JPS joint position sense, na not applicable, SEM standard error measurement.
* The same test leader was used for both season one and two.

4.3.2 Risk estimates

The HRRs of shoulder injuries for the different preseason clinical shoulder tests are presented in Table 15. The HRR for IER strength was 2.37 (95% CI 1.03-5.44) in female players and 1.02 (95% CI 0.44-2.36) in male players. The HRR for IIR strength was 2.44 (95% CI 1.06-5.61) in female players and 0.74 (95% CI 0.31-1.75) in male players. There was no association between ROM and shoulder injuries in either sex. The HHR for scapular dyskinesia during abduction was 1.53 (95% CI 0.36-6.52) in female players and 3.43 (95% CI 1.49-7.92) in male players, but no association was observed during flexion. Finally, there was no association between JPS and shoulder injuries in either sex.

Table 15. Hazard rate ratios of shoulder injury in the dominant arm in female and male adolescent handball players.

	Females Player seasons=226 (n=180)			**Males** Player seasons=226 (n=164)		
	Exposed cases/ exposed non-cases	**Crude HRR (95% CI)**	**Adjusted HRR* (95% CI)**	**Exposed cases/ exposed non-cases**	**Crude HRR (95% CI)**	**Adjusted HRR* (95% CI)**
Strength (N/Kg)						
ER	22/122	2.37 (1.03-5.45)	2.37 (1.03-5.44)	9/86	0.99 (0.43-2.28)	1.02 (0.44-2.36)
IR	22/148	2.43 (1.06-5.58)	2.44 (1.06-5.61)	6/71	0.66 (0.28-1.55)	0.74 (0.31-1.75)
EER	20/117	1.25 (0.58-2.71)	1.21 (0.57-2.62)	7/81	0.64 (0.27-1.50)	0.70 (0.29-1.64)
IABD	19/137	1.14 (0.53-2.47)	1.10 (0.50-2.38)	9/62	1.13 (0.49-2.62)	1.19 (0.51-2.77)
IER:IR <0.75	5/53	0.87 (0.40-1.87)	0.85 (0.39-1.83)	11/82	2.04 (0.69-6.04)	2.00 (0.68-5.92)
ECC:IIR <0.75	5/49	0.45 (0.11-1.88)	0.41 (0.10-1.73)	10/87	1.08 (0.44-2.66)	1.10 (0.45-2.69)
Range of motion (°)						
ER	11/104	0.71 (0.33-1.55)	0.74 (0.34-1.62)	10/113	0.84 (0.36-1.95)	0.74 (0.31-1.73)
IR	11/82	1.56 (0.70-3.51)	1.59 (0.70-3.54)	16/131	1.06 (0.46-2.44)	1.03 (0.45-2.37)
TROM	9/78	0.70 (0.32-1.53)	0.70 (0.32-1.53)	14/129	0.87 (0.37-2.00)	0.77 (0.33-1.81)
TROM dominant vs. non-dominant shoulder	14/106	1.21 (0.56-2.62)	1.30 (0.59-2.83)	8/104	0.56 (0.24-1.35)	0.53 (0.22-1.25)
Scapula dyskinesia**						
During flexion	4/53	0.50 (0.17-1.45)	0.49 (0.17-1.44)	16/129	1.44 (0.56-3.67)	1.53 (0.60-3.94)
During abduction	2/8	1.65 (0.39-6.98)	1.53 (0.36-6.52)	11/40	3.45 (1.49-7.95)	3.43 (1.49-7.92)
Joint position sense						
Mean error from TA	12/98	1.06 (0.49-2.29)	1.06 (0.49-2.29)	12/107	1.14 (0.49-2.63)	1.12 (0.48-2.59)

CI; confidence interval, EER Eccentric external rotation strength, EER:IR a ratio where EER is divided with IR, IABD isometric abduction strength, IER Isometric external rotation strength, IER:IIR a ratio where ER is divided with IR, ER External rotation, HRR Hazard rate ratio, IIR Isometric internal rotation strength, IR internal rotation, N/Kg Newton per Kilogram, TA target angle, TROM total range of motion (IR+ER)

* Adjusted for playing position

** The analyses in female players is based on 225 player seasons due to one player who denied to perform this test

5 DISCUSSION

5.1 Main findings

5.1.1 Prevalence of shoulder problems and pain (Study I)

To the best of my knowledge, this is the first study to compare the prevalence of shoulder problems between sex, school grade, playing position and level in handball. The main finding, that almost one in four players reported having substantial shoulder problems at some point during a handball season, is almost as high as has been reported in adult players.

5.1.1.1 Prevalence and persistence of shoulder problems

One essential first step in constructing injury prevention measures is to describe the prevalence and burden of injuries (61, 62). We found that the average season and average weekly prevalence of substantial shoulder problems in adolescent players was 23% and 6%, respectively. This is in line with the prevalence reported in previous studies on adolescent (94) and adult players in Norway (40, 44, 74) (Table 3). Aasheim et al. reported an average weekly prevalence of any and substantial shoulder problem of 17% and 7%, respectively. Clarsen et al. reported a season prevalence of substantial shoulder problems in the dominant shoulder in of 28% and an average weekly prevalence of 12% in adult male players in Norway (40). This is somewhat higher compared to Andersson et al. (44), who reported an average weekly prevalence of 8% in the control group of an RCT in male and female adult players, and Clarsen et al. (74), who reported an average weekly prevalence of 6% in a mixed population of male and female adult and female junior players from Norway. Moreover, our results are also comparable to a study on adolescent volleyball players from Norway, where an average week prevalence of substantial shoulder problems of 5% was reported (74).

We also found a lifetime prevalence of shoulder pain of 46% in females and 35% in males, which is in line with the lifetime prevalence of shoulder pain of 44% in adult Iranian male and female handball players (95). However, our findings are lower than reports of current shoulder pain (49%) and one-year prevalence (63%) in amateur adolescent handball players from Brazil (97) and on elite female players in the Norwegian first division, where 57% reported to be affected by previous or current shoulder pain (48). It makes sense that the adult elite population has a higher prevalence of shoulder pain and problems since we found that shoulder problems in our population seem to be persistent and recurrent, with two thirds of those reporting shoulder problems the preceding season also reporting problems during the following season.

5.1.1.2 *Sex differences*

Interestingly, we found a significantly higher prevalence of shoulder problems in female players, regardless of the definition of shoulder problems. Similar sex-related differences have been reported in adult elite players in Norway, where female players had a higher avarage weekly prevalence of shoulder problems compared with male players (26% vs. 20%) (44). This has also been reported in adult players in Brazil on traumatic shoulder injuries and a cumulative season incidence of 9% in females and 3% in males (70). However, our findings are not in line with the findings of a previous study on youth handball players, where no sex-related differences in the incidence of shoulder injuries were found (73). Sex-related differences for shoulder injuries have been reported in other overhead sports such as water polo, lacrosse (52) and also for other severe injuries in team sports such as ACL injury (115, 116), and concussion (117).

Importantly, the lifetime prevalence of shoulder pain in our study was also higher in females. Consequently, shoulder problems likely occur earlier in the handball career in female players compared with male players, and this phenomenon would in that case be comparable to the relative age effect recognised for ACL injuries in football (116). One factor that may influence the risk of developing shoulder problems in handball is potential sex-related differences in workload, since adult female players have demonstrated a higher relative workload compared with male players (9). However, there are no studies that have compared relative workload in adolescent players. Another plausible explanation is potential sex-related differences in throwing kinematics and technique. The different types of throw (whip-like and circle-like) potentially create different amounts of load on the shoulder (23). Even though there are studies reporting sex-related differences in throwing kinematics (118, 119), a more recent systematic review concluded that timing sequence, joint angles and joint velocities were not affected by sex, and that the comparability between the studies was limited due to methodological differences (10). Furthermore, all of the studies in throwing kinematics in handball are conducted on adult players and it is unclear if the knowledge gained here is transferrable to adolescent players.

5.1.1.3 *School grade differences*

We found no difference in season prevalence of shoulder problems between the school grades when measured prospectively. Remarkably though, when measuring retrospectively, substantial shoulder problems were more common in 2nd and 3rd grade students compared with 1st grade students (20% vs. 8%). This could be due to the persistence of shoulder problems. Moreover, it could be also be due to a potential increase in physical and psychological demands between the season before and the first season at a handball-profiled secondary school. Contrary to our findings, a previous study on Danish Under-16 and Under-18 players did not find any age-differences in shoulder injuries (73). However, notably the differences in injury definition in the two studies may explain the discrepancy.

5.1.1.4 Playing position differences

We found a higher prevalence of shoulder pain in backcourt players compared with wing and line players, regardless of prevalence definition. These results are perhaps less surprising, since backcourt players have a higher shoulder-specific stress on the shoulder, mostly due to the fact that they make most of the high velocity throws during a match compared to wing and line players. However, backcourt players often play in mid-defence, which includes more blocking, screening and tackling compared with the wing players, and this also increases the demand on the shoulder (8). These findings are also in line with previous reports from adult male players in Norway (40) and adolescent female players in Denmark, where backcourt players had a higher overall incidence rate compared with goalkeepers and wing players (65, 66). Notably, in a more recent study on younger players (aged 13-14), no playing position differences were found, which could be explained by the age and injury definition differences between the studies (92). One potential explanation could be that, at that age, the players more often play in different playing positions compared to adults and older adolescents.

5.1.1.5 Playing level differences

Regardless of prevalence definition, we found no differences in the prevalence of shoulder problems between players competing at a national level and those playing only at a regional level. The most plausible explanation here could be that all participants already played handball at a high competitive level with negligible additions in the number of matches played and other workload-related variables. This finding is in line with those of a study on adult male handball players in Norway, which reported no association between playing level and shoulder injuries (40).

5.1.2 Shoulder strength differences between sex and playing positions (Study II)

To the best of my knowledge, this is the first study that describes shoulder strength reference values in adolescent elite handball players, stratifying by sex, playing position, school grade and playing level. The main findings were that male players were stronger than female players, both in terms of absolute strength and when normalised by bodyweight. Moreover, both male and female backcourt players and wing players were stronger than goalkeepers and line players, and there was a side-to-side difference in both females and males in favour for the dominant arm in all measures.

5.1.2.1 Reliability of the strength measurements

The intra-rater reliability for the shoulder strength tests was excellent in males and good to excellent in females. This is comparable with other studies on youth handball (37, 75) as well as other adult overhead athletes (112, 113). The minimal detectable change (MDC) was between 15-19% in male players and 15-20% in female players, depending on strength variables, which is comparable with previous studies on adult handball players (112).

5.1.2.2 Reference values

The reference values in IER, IIR and EER in our study are in line with a previous study on adult players using the same test procedure (41). However, there were lower compared to a recent study on youth players (39). This was quite surprisingly since the players in that study had an average age of 14.1 years, which is two years younger compared to the average age of the population in our study. The reference values in IABD for the male players in our study is somewhat lower compared to previous reports on adult male players which is what one can expect because of the age difference (40). Comparing the reference values to others studies on adolescent players is hard since these have used different test positions and/or test equipment (35, 36, 38).

5.1.2.3 Sex differences in shoulder strength

The male players were stronger in both dominant and non-dominant arm, compared to female players, regardless of normalisation by bodyweight or not. This is comparable with previous studies on handball players (41, 44, 120), and other overhead sports (41, 121, 122). However, this is in contrast to a recent study on youth handball players in Germany using the same test protocol as in our study, where the male players were stronger in terms of absolute strength, but not when normalised by bodyweight (39). Again contrary to our study, Cools et al. found that adult female handball players were stronger in IER when normalised by bodyweight (41). These discrepancies compared with our study may be explained by differences in age and playing level of the study participants.

5.1.2.4 Playing position differences in shoulder strength

To the best of my knowledge, there are no previous studies comparing shoulder strength in adolescent handball players between different playing positions. Overall, and less surprisingly, male backcourt and line players were stronger than goalkeepers and wing players in terms of absolute strength. However, both male and female backcourt players and wing players were stronger compared with line players and goalkeepers when normalised by bodyweight. Consequently, it should be recommend to take both playing position as well as normalisation by bodyweight into account when measuring, comparing and interpreting shoulder strength values in adolescent handball players. Finally, this finding is also clinically relevant, since backcourt players have been reported to be more susceptible to shoulder problems than other playing positions (40). It could be so that certain playing positions e.g. backcourt players require greater shoulders strength due to the higher demand on the shoulder.

5.1.2.5 School grade differences in shoulder strength

In males, older players (2nd and 3rd grades) were stronger than younger players (1st grades), but when normalised by bodyweight this difference disappeared. No school grade differences were found for absolute strength including when normalised by bodyweight in females. This non-difference in strength between different age groups when normalised by bodyweight is comparable with reports on other overhead sports such as tennis and swimming (121, 123). It is noteworthy that the female players in our study did not show any differences in shoulder strength during their three-year period at a handball-profiled secondary school. It is doubtful that growth maturity per se would be a significant primary factor here, since several previous studies have shown that other strength and power measures such as bench press, counter movement jumps, deep squat and clean jerks could be improved significantly during this age period in female players (124, 125). The lack of increased shoulder strength in females during this period is a novel and interesting finding that could contribute to the higher prevalence of shoulder problems seen in the female players in this thesis.

5.1.2.6 Playing level differences in shoulder strength

In male players, national level players were in general stronger compared with regional level players, however there were no differences when normalising strength by bodyweight. In females, there were in general no differences between national players and regional players expect hat national players were stronger in EER in the dominant arm and in IABD in the non-dominant arm in terms of absolute strength, but not when normalised by bodyweight. Although studies on adolescents are lacking in this respect, a few studies have compared other strength and power values in adult players of different playing levels. National Brazilian Olympic team players have been reported to perform better in bench press exercises, loaded jump squats and countermovement jumps compared with national college players (126). In addition, Haguen et al. reported that Norwegian male handball players at the national team level were stronger in squats, countermovement jumps and 1-repetition maximum (RM) bench press compared to those not playing for the national team (127). Similarly, Granados et al. reported that Spanish female players who were at the international level were stronger in 1RM bench press compared with national players (128).

5.1.3 Risk factors for shoulder injuries (Study III)

In this prospective study we investigated the association between shoulder strength, shoulder ROM, scapula dyskinesia the incidence of shoulder injuries in male and female adolescent elite players separately. The main findings in this study were that female players with shoulder IER or IIR weaknesses, measured during the pre-season and male players with scapular dyskinesia during abduction measured during pre-season had a significantly higher risk of shoulder injury during the competitive season.

5.1.3.1 Outcome (injury definition)

Injury was based on the OSTRC overuse questionnaire and we used the cut-off score of 40 or more to define an injury. The same cut-off score has been used in other recent studies on handball players, but in these studies the score was based on the average season prevalence and not the weekly reports of incidence (40, 44 74). Another commonly used outcome based on the same questionnaire is "any shoulder problems" or "substantial shoulder problems", as was used in Study I. These outcomes are based on the specific answers to questions about reductions in sports participation or performance. In Study I, this definition was used to describe shoulder problems so that our results could easily be compared to other studies on handball players and other adolescent sports, e.g. volleyball (40, 44, 74, 94). In Study III we a priori chose the injury definition of a score of 40 or more on the OSTRC overuse injury questionnaire since we also sought to capture pain. Moreover, when using just one specific answer in questionnaires to define injury there is a potential risk of misclassification if players tick the wrong answer by accident. By using an injury definition based on the result of several questions e.g. a composite score this potential risk of misclassification is reduced.

5.1.3.2 Shoulder strength and shoulder injuries

In female players, there was an association between IER and IIR weakness individually and the risk of shoulder injuries. In previous studies in adult and adolescent handball, shoulder strength impairment has been shown to be associated with shoulder injuries (36, 39, 40, 43, 75). Edouard et al. found that external rotation weakness was associated with shoulder injuries in a population of French female junior national players, which is in line with our results (36). However, this study had only 17 participants with less than 10 exposed cases. External rotation weakness was also associated with shoulder injuries in a recent study on German youth players (39). Direct comparison to our results is, however, difficult, since they did not stratify all of their analyses by sex. In the same study, the authors also measured the IIR strength, but no results were reported (39). Moreover, the response rate to the five follow-up questionnaires during the season was quite low in that study; 44% answered all five questionnaires, which increases the risk of selection bias (39). In a recent study on Danish youth players, shoulder weakness, i.e. low external to internal rotational strength ratio, was found to be an effect modifier on handball load. However, in that study the analyses were not stratified by sex, and it is therefore difficult to compare those results to our results on females and males respectively (75). The other two studies are on adult male players in France (43) and Norway (40); where the first reported that internal rotational weakness was associated with traumatic shoulder injuries (43) while the latter reported that external rotational weakness was associated with shoulder problems (40). However, the latter could not be confirmed in a more recent study with a mixed population of male and female players (44). Compared to other studies, our study and a recent by study Achenbach et al. are (39), to the best of my knowledge, the only prospective studies measuring internal rotation strength with the shoulder in a seated 90-90 position, which is similar to the cocking phase of throwing. This difference in test position could be one explanation why we found IR to be a risk factor while most other studies have not (36, 40, 44). Difference in throwing biomechanics might explain why we found that shoulder weakness was a risk factor in female, but not in male, players. Female players may have a throwing motion or might more often use a throwing technique that hypothetically puts a greater demand on the shoulder, particularly rotational strength (118). Nevertheless, these results are inconsistent (10, 119), and there are to date no studies on sex differences in throwing biomechanics in adolescent handball players.

5.1.3.3 Shoulder ROM and shoulder injuries

There was no association between ROM measured at baseline and shoulder injuries in either male or female players. This is in line with a recent study on youth elite handball players (75), and also studies on other overhead athletes (104, 105, 129, 130). However, there is a discrepancy with another recently published study on youth handball players from Germany, which found an association between increased ROM and shoulder injury in females, but not in males (39). Previous studies on professional male and female handball players in Norway have reported an association between ROM and shoulder problems, where one study with only male players reported that decreased external rotation was associated with shoulder injuries (40), while a more recent study with both male and female players could not confirm the findings and, on the contrary, reported that increased internal rotation was associated with a higher risk (44).

There are many reasons that might explain the different results in previous studies regarding the association between ROM and shoulder injuries. First, ROM may be a risk factor for adult players, but not for adolescent players. Second, a recent study reported that shoulder ROM measured passively in a handball player on the treatment table does not automatically correlate with the shoulder ROM that the player achieves during the handball throw (49). If ROM measured outside of the authentic throwing environment e.g. measured passively on the treatment table, is prone to considerable misclassification it will most likely result in a dilution of true associations. Finally, there are several biological structures that might limit the shoulder ROM, such as the joint capsule, soft tissue tightness around the scapula and glenohumeral joint and the retrotorsion of humerus (131). These biological structures all potentially play different roles in the association with shoulder injuries and unless all these factors are considered it is difficult to make any strong assumptions concerning shoulder ROM assessed passively on the treatment table.

5.1.3.4 Scapular dyskinesia and shoulder injuries

There was an association between scapular dyskinesia during glenohumeral abduction and risk of shoulder injuries in male players, which extends to previous research in handball (40, 75). We did not find an association between scapula dyskinesia during glenohumeral flexion and shoulder injuries. This makes sense because this movement is closer to the throwing position in handball (10). Further, my clinical experience is that scapula dyskinesia is present during glenohumeral flexion in many adolescent players, especially during the final motion of eccentric flexion and especially in male players. Notably, there was no association between scapular dyskinesia during flexion or abduction and shoulder injuries in female players. In contrast to our results, a recent study on German youth players could not find an association between scapula dyskinesia and shoulder injury (39). However, the analyses were not stratified by sex so direct comparison with our results are hard. Further, the players in that study were an average two years younger which could explain the diversity of the results (39). Moreover, a previous study with a mixed cohort of male and female adult players in Norway did not find an association between scapula dyskinesia and shoulder injuries (44). No stratification by sex was made in the analyses so direct comparison to our results are hard. Again, this could be explained by any potential difference in throwing biomechanics, as discussed above. However, the lack of association could also be due to exposure misclassification or too few exposed cases and low statistical power, as discussed below.

5.1.3.5 JPS and shoulder injuries

There was no association between JPS and shoulder injuries in either the males or the females. This is, to the best of my knowledge, the first study to prospectively investigate JPS and future shoulder injuries in throwers so comparison to previous results is hard. There are several studies where the relationship between JPS and performance have been studied and compared between throwers with non-throwers (132-135). But, the results are inconclusive, where one study reported no differences between throwers and non-throwers (132), another reported in favour of non-throwers (133) and yet another reported in favour of the throwers (134). Furthermore, it has been reported that JPS is not related to throwing speed or accuracy in adolescent male baseball players (135).

5.2 Methodological considerations

The research results must always be interpreted in the framework of the study designs and methods used.

5.2.1 Random errors

Regardless of study design, random errors can occur in every study. A random error is an error that remains after systematic errors are eliminated and is entirely associated with chance. In contrast to a systematic error, a random error is reduced with a larger sample size, i.e. a larger study size increases the precision of the estimates (136).

The studies in this thesis are based on a large and homogenous cohort of athletes, which reduces the risk of random errors for the main outcomes. However, the statistical power could be lower in some sub-analyses introducing an increased risk of random errors.

5.2.2 Systematic errors

In contrast to random errors, systematic errors are independent of the study sample size and are prone to reduce the internal validity in observational studies. Systematic errors can be divided into three subgroups; selection bias, information bias (misclassification) and confounding.

5.2.2.1 Selection bias

Selection bias arises from measures used to select study participants and from factors that effect the study participation and arises when the association between exposure and the event e.g. injury differ from those who participate in the study and those who do not participate in the study (136).

5.2.2.2 Information bias (misclassification)

This type of error arises when the information collected about or from the study subject is inaccurate, which is often referred to as misclassification. If a variable is measured on a categorical scale, e.g. scapula dyskinesia (exposure) or shoulder injury (outcome) and the error leads to a player being placed in an incorrect category of exposure or outcome, the player is misclassified. Misclassifications can be differential or non-differential. If the misclassification of the exposure and outcome is unrelated it is defined as non-differential, while, if related, it is defined as differential misclassifications.

5.2.2.3 *Confounding*

A simple definition of confounding is the confusion or mixing of effect (136). It arises when the association between an exposure and outcome is skewed by a third variable (confounding factor). According to Rothman, a confounding factor must have three associations: "1) be associated with the outcome (either a cause or a proxy for a cause, but not as an effect of the outcome), 2) be associated with the exposure, and 3) not be an effect of the exposure itself" (136).

5.2.3 Overall strengths and limitations with the Karolinska Handball Study

5.2.3.1 *Strengths*

An overall strength with KHAST is the large sample size (471 players with 622 player seasons) with an equal distribution of female and male players, and most likely representative of the total population of adolescent elite handball players in Sweden (Study I-III). Moreover, the high response rate throughout the follow-up period ensured a low risk of selection bias (Study I & III). There were no differences in the exposure values at baseline between players who dropped out or completed the study, or between players with low and high response rates, which minimises the risk of selection bias even further (Study I & III). Moreover, in this study valid questionnaires that are widely used were used to obtain data (64, 110), which reduces the risk of misclassification of both exposure and outcome (Study I-III). Furthermore, the reliability of the clinical measures used was good to excellent. This also reduces the risk of misclassification of exposure (Study II-III). Additionally, female players and backcourt players had a significantly higher prevalence of shoulder problems regardless of the definition of shoulder problems, which also indicates a low risk of misclassification (Study I). Finally, we collected information about a long list of potential confounders (Study III) enabling adjusting for confounding. The equipment used for clinical measures was field-friendly and relatively cheap, which enables practitioners to use the same methods in their clinical setting (Study II-III).

5.2.3.2 *Limitations*

Some limitations of the studies in this thesis should also be noted. First, roughly one out of seven eligible player did not consent to participate in the study (107). This could potentially introduce selection bias, for instance if the players who did not consent to participate differ from those who consented by having less shoulder problems or being stronger. However, the main reasons for not participating were that players did not obtain written consent from their legal guardians on time or that players were scheduled for out-of-school practice during the inclusion period. Those who had these reasons not to participate probably do not differ from the participating players in a way that would result in selection bias. Second, another limitation that potentially could result in a risk of misclassification of the outcome is the reporting of any previous shoulder pain or shoulder problems during the preceding season or the past two months. The questionnaire used was originally designed to report shoulder problems during the past week (Study I & III), and the longer recall period may result in an underestimation of the prevalence, which may explain why the prevalence reported for the preceding season was lower compared with the follow-up season (Study I). A long recall period could also lead to mistakes when identifying a healthy cohort at the study start (Study III). If a player cannot remember the extent correctly, e.g. report fewer problems than he or she actually had during the past two months, he or she may be wrongly classified as healthy and thus included in the analyses on risk factors (Study III).

In addition, although the reliability of identifying scapula dyskinesia was found to be good, there is a risk of misclassification of scapular dyskinesia in female players as their sports bras might obscure a visual identification of the scapular dyskinesia. This would potentially lead to an underestimation of the number of female players in cohort who had scapula dyskinesia (Study III). Furthermore, there is a potential risk of non-differential misclassification of strength in the male players (Study II-III). Since rotational strength was assessed in a seated position with the shoulder in the "90-90 position", the players were close to their maximum external rotational ROM, which could have influenced the IER strength more in male players because they often have less external rotational ROM. These potential misclassifications of shoulder strength and scapula dyskinesia might explain why strength was found to be associated with shoulder injuries in females while in males, scapula dyskinesia was found to be associated with shoulder injuries (Study III). Third, follow-up data were self-reported on a weekly basis and players might have experienced problems in recalling the exact time at risk during the past week, i.e. minutes of handball match and handball training. However, these potential misclassifications are non-differential as they are most likely not associated with the exposures measured at baseline (Study III).

Fourth, because several tests of statistical significance were performed to investigate differences in shoulder strengths in different players characteristics; there might be a risk of introducing random errors. However, because most of the comparisons in strength demonstrated a low p-value (<0.005), I judge the risk of random errors to be low (Study II). Fifth, this study might be underpowered for investigating prevalence differences between school grades (Study I), shoulder strength differences between some playing positions such as line players versus goalkeepers (Study II), and scapular dyskinesia in female players (Study III). Thus, the results of some sub-analyses involving few cases or events should be interpreted with caution.

Sixth, the number of missed days, training sessions or matches was not recorded as well as any specific shoulder diagnoses, because the OSTRC overuse injury questionnaire was used (64, Appendix B) (Study I & III). Consequently, the injury severity based on number of days missed, and the prevalence and incidence of specific diagnoses could not be reported. However, 88% of the shoulder injuries reported during follow-up period were overuse injuries, which are rarely related to a specific pato-anatomical injury. In other overhead sports with a frequent throwing or overhead propelling motion, e.g. baseball or volleyball, the majority of overuse shoulder injuries are diagnosed as tendinopathies (52).

Seventh, there are also potential limitations related to the clinical measurements used. A typical limitation with HHD strength tests is that the reliability and validity is reliant on the fact that the one doing the test is stronger than person that is tested, especially when testing eccentric strength, and this may be a challenge, particular in elite athletes (Study II-III). Moreover, it is also reliant on the fact that the tester is giving the same amount of external support during the test. For instance with more support and stability of the arm, the players can potentially produce greater forces. Any diverse in external support given during the test in our study and a recent study on youth player could potentially explain the difference in strength between the two study populations (39). We did not use any external fixation, which could have increased the stability during the tests, and potentially could have improved the reliability measures (Study II-III); however, the ICCs for the tests were good to excellent in spite of no external fixation.

Eighth, we collected data to control for a large number of a priori defined potential confounders. However, the number of injuries restricted the possibility to include several confounders in the same model (Study III). Hence only playing position was included and adjusted for in the adjusted model as per request from the journal peer-review process. Nonetheless, we performed three sensitivity tests where other a priori chosen potential confounders; school grade, school and playing level were included one at the time in the model. These analyses did not change the main results in Study III.

Finally, we did not collect information about sleep patterns or nutritional intake. A previous study has reported an association between sleep patterns and nutritional intake and sports injuries in adolescent athletes (137). Therefore, these results may be disposed to residual confounding. Importantly though, any potential residual confounding is unlikely to affect the strong risk estimates found for IER and IIR in female players and for scapular dyskinesia in male players (Study III).

5.2.4 Generalisability

Generalisability can be described as a measure of how well the findings obtained from the selected study population can be extended to the population as a whole, i.e. the population that the study sample aims to represent. This is also referred to as the study's external validity. Importantly, all the studies within this thesis are based on data from KHAST, which, in my opinion, should be representative for the adolescent elite handball players in Sweden, including a low risk of selection and information bias. Moreover, since many of the overhead motions are similar in most overhead sports, the findings on risk factors for overuse shoulder injuries could most likely be generalised to other overhead sports (Study III).

6 FUTURE PERSPECTIVE

This thesis has deepened the available knowledge about shoulder injuries in adolescent elite handball players. This is a relatively unexplored research field and the results in this thesis will contribute to new ideas, studies and interventions. Our results suggest that the prevalence of shoulder problems in adolescent elite handball players is almost as high as seen in professional players. Consequently, for any future aim to reduce primary shoulder problems in handball, the focus should be on adolescent players and even more preferably before the age of 16, since 20% already report shoulder problems at this age. Furthermore, these findings also highlight the importance of medical support for this age group.

Less surprisingly we found that there was a difference in shoulder strength between male and female players. Perhaps more interesting and clinically meaningful was that there were sex-related differences in the prevalence of shoulder problems where female players with shoulder rotational weakness and males with scapular dyskinesia had higher injury rates. This highlights that sex-related differences in shoulder injury risk factors should be considered routinely and further investigated in future studies. Moreover, this also opens up for an investigation of whether the effect of shoulder injury preventative strategies differs between male and female players. The same holds true for playing position, where there were not only differences in the prevalence of shoulder problems, but also in strength reference values between the different playing positions. Since both the handball demands in general and the shoulder demands specifically, differ between the playing positions, certain exposures might have a larger effect on the risk of shoulder injuries in certain playing positions, e.g. backcourt players. An important objective for future studies in the field is to investigate if there are any differences in risk factors between the playing positions. This requires a considerably larger study sample, which can probably be achievable through multicentre studies or large cohort studies performed over a very long consecutive time period.

Before preventive measures can be designed, studies investigating the incidence and prevalence (injury burden) as well as identifying risk factors must be performed. The results from this thesis show that already by the mean age of 16, many handball players at an elite level suffer from shoulder problems, which are often persistent, and this high burden warrants preventative strategies. It is not acceptable that around every fourth player cannot perform at his or her peak capacity due to shoulder problems. This is not just a potential risk for the player to quitting sport due to persistent injuries but also a risk for not reaching his or her full athletic potential.

The results on risk factors are in line with recent studies, and these results can indicate that it could be a good idea to investigate if measures aiming to reduce these factors have a preventative effect on shoulder problems. This needs to be evaluated in a clinical trial, preferably in an RCT. Moreover, it would be preferable that not only injury risk reduction should be measured in such an RCT, but also if the factor that was intended to be reduced through the intervention, e.g. shoulder strength, actually is reduced.

7 CONCLUSIONS

Among adolescent elite handball players, the season prevalence of substantial shoulder problems is high (23%), and higher in female players (28%) and backcourt players (33%). Shoulder problems were also persistent with about two thirds reporting consistent shoulder problems (Study I).

Male players were stronger than female players in both the dominant and non-dominant shoulders, both in terms of absolute strength and when normalised to bodyweight. In general, wing players were stronger than line players when normalised to bodyweight (Study II).

In female players entering the handball season with shoulder internal or external rotation weakness there is almost a three-fold higher risk of developing shoulder injuries in the dominant arm, while in male players entering the handball season with scapular dyskinesia during abduction there is more than a three-fold higher risk of shoulder injuries in the dominant arm (Study III).

8 POPULÄRVETENSKAPLIG SAMMANFATTNING

Handboll är den fjärde vanligaste lagidrotten i Sverige, med 130 000 aktiva utövare. Handboll är en fysiskt krävande bollsport, som innefattar snabba löpningar, sidledsförflyttningar, hopp, kampmoment med motståndare samt skott och passningar. Handboll är också en av de mest skadedrabbade idrotterna med högt antal rapporterade skador där knä, fotled, fingrar och axel är de vanligast förekommande skadelokalisationerna. Bland knä-, fotleds- och fingerskador är akuta skador vanligast förekommande medan de allra flesta axelskador utgörs av överbelastningsskador.

Det övergripande målet med denna avhandling var att fördjupa kunskapen kring hur vanligt det är med axelskador hos handbollsspelare som studerar vid handbollsgymnasier, men också att jämföra om det är någon skillnad i förekomst av axelskador beroende på kön, spelarposition, ålder samt vilken nivå man spelar på. Slutligen var ett av huvudmålet med avhandlingen att undersöka potentiella riskfaktorer för att få axelskador.

I detta projekt så deltog 471 handbollsspelare från 10 NIU-gymnasier med handbollsprofil. Andelen spelare som hade axelproblem någon gång under handbollssäsongen var 44 % och hela 23 % av alla uppgav att de hade haft betydande axelproblem definierat som så pass mycket besvär att de hade ändrat sin träning eller presterade sämre. Detta innebär att det nästan är lika vanligt med axelproblem hos handbollsspelare vid handbollsgymnasier som hos seniorspelare på elitnivå. Axelproblemen är dessutom vanligare hos tjejer, där 27 % av spelarna någon gång under handbollssäsongen uppgav att de hade betydande axelproblem jämfört med killar där motsvarande siffra var 19 %. Det var också vanligare med axelproblem hos 9-metersspelare jämför med linje- och kantspelare. Vi fann också att andelen som hade axelskador var betydligt lägre året innan de börjar på handbollsgymnasiet, 8 % jämfört med 20 %.

Hos tjejerna fann vi ett samband mellan uppmätt axelstyrka under försäsongen och risken att få en axelskada under efterföljande tävlingssäsong. De som hade lägre axelstyrka hade nästan tre gånger högre risk att drabbas av en axelskada i sin dominanta axel. Hos killarna sågs inte detta samband, utan istället fann vi att de som hade ett avvikande rörelsemönster i sitt skulderblad, så kallad skapuladyskinesi, hade mer än tre gånger så hög risk att drabbas av en axelskada.

Dessa fynd belyser att det är relativt vanligt med axelskador redan i ung ålder och att strategier för att förebyggande dessa är nödvändiga. Vidare belyser detta att det kan finnas en skillnad i mekanismerna bakom axelskador hos tjejer och killar och att det bör utvärderas ytterligare eftersom strategier för att minska axelskador kan ha olika effekt hos tjejer och killar.

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APPENDIX A

FRÅGFORMULÄR ANGÅENDE SKULDERPROBLEM I HANDBOLL

1. Jag har fått muntlig och skriftlig information om studien och accepterar att delta i denna

☐ JA

2. Namn:____

3. Gatuadress:____

4. Postnummer:____________Postort:______________________________________

5. E-postadress:____

6. Telefonnummer:

Dagtid:______________________________Kvällstid:__________________________

7. Personnummer: ____

8. Ålder:____

9. Kön: ☐ Man ☐ Kvinna

10. I vilken gymnasieskola går du?

____

11. På vilken nivå spelade du under den senaste säsongen? (Kryssa i den högsta nivån du uppnådde)

☐ Uttagen till landslagsturnering (högsta)

☐ Uttagen till riksläger

☐ Uttagen till distriktslag

☐ Spel i förening/klubblag (lägsta)

12. Är du vänster- eller högerhänt?

☐ Vänsterhänt ☐ Högerhänt

13. Vilken spelarposition har du? (Spelar du på flera positioner, välj den position du oftast har)

☐ Vänster 9 ☐ Mitt 9 ☐ Höger 9

☐ Vänsterkant ☐ Linje ☐ Högerkant ☐ Målvakt

14. Hur många matcher per vecka spelade du i genomsnitt under den senaste handbollssäsongen? (Antal matcher/vecka i snitt)_________

15. Hur många timmar per vecka tränade du i genomsnitt handboll på handbollsplan under den senaste handbollssäsongen? (Antal timmar/vecka i snitt) _________

16. Hur många timmar per vecka tränade du i genomsnitt handbollsinriktad träning som inte är handbollsspel under den senaste säsongen? (Exv. fysträning, löpning, styrketräning) (Antal timmar/vecka i snitt) _________

17. a. Tränar du regelbundet specifika vridövningar för dina skuldror under handbollssäsongen? (Se exempel på övningar nedan)

☐ Nej

☐ Ja

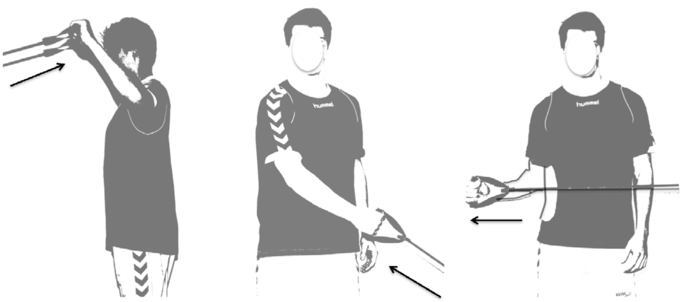
b. Om Ja, hur ofta? (Antal tillfällen/vecka)_______________

c. Tränar du regelbundet specifika vridövningar för dina skuldror under sommarlovet? (Se exempel på övningar nedan)

☐ Nej

☐ Ja

d. Om Ja, hur ofta? (Antal tillfällen/vecka)_______________



e. Hur ofta har du under det senaste sommarlovet utfört handbollsskott? (Med handbollsskott menas kast med handboll med maximal eller nästan maximal kraft) kryssa i det alternativ som stämmer bäst in.

☐ Aldrig
☐ Sällan
☐ Ibland
☐ Ofta
☐ Mycket ofta

Frågor om träning och match föregående säsong med högre åldersklass
(med högre åldersklass menas att du t.ex. är junior och spelar med A- eller B-laget eller att du är A-pojk-/flickspelare och spelar med juniorer)

f. Hur ofta har du under föregående säsong haft handbollsträning med högre åldersklass än den du tillhör? kryssa i det alternativ som stämmer bäst in.

☐ Aldrig
☐ Sällan
☐ Ibland
☐ Ofta
☐ Mycket ofta

g. Hur ofta har du under föregående säsong spelat handbollsmatcher med högre åldersklass än den du tillhör? kryssa i det alternativ som stämmer bäst in.

☐ Aldrig
☐ Sällan
☐ Ibland
☐ Ofta
☐ Mycket ofta

18. a. Förutom handboll, utövar du någon annan idrott eller regelbunden fysisk aktivitet som inte är handbollsrelaterad? (Exv. annan idrott, klättring, mountain-biking etc.)

☐ Nej

☐ Ja

b. Om Ja, vilken annan idrott eller fysisk aktivitet? ________________________________

c. Om Ja, ange genomsnittligt antal timmar per vecka__________

19. Hur många år har du spelat handboll? ___________

Skuldersmärta

20. a. Har du någonsin haft ont i någon skuldra i samband med handbollsspel?

☐ Nej

☐ Ja

b. Om Ja, vilken skuldra? ☐ Vänster ☐ Höger ☐ Bägge

Skulderproblem den <u>senaste säsongen</u>

Nedanstående frågor gäller endast eventuella skulderproblem som du har haft under den senaste säsongen, dvs. inte längre tillbaka i tiden än så, och även om du inte har några skulderproblem just nu.

Vänligen svara på alla frågor nedan oavsett om har haft besvär eller inte i skuldran. Välj det svarsalternativ som är mest passande för dig. Om du är osäker så försök att svara så gott du kan.

Med skulderproblem menas smärta, värk, stelhet, överrörlighet eller andra problem i axel och skuldra.

21. Har du under den <u>senaste säsongen</u> haft svårigheter med att delta i din idrott (ordinarie träning/match/tävling) på grund av skulderproblem?

☐ Deltagit för fullt, utan skulderproblem
☐ Deltagit för fullt, men med skulderproblem
☐ Minskat deltagande, på grund av skulderproblem
☐ Ej kunnat deltaga, på grund av skulderproblem

22. I vilken grad har du under den <u>senaste säsongen</u> minskat på träningsmängden på grund av dina skulderproblem?

☐ Ingen minskning
☐ I liten grad
☐ I måttlig grad
☐ I stor grad
☐ Ej kunnat deltaga, på grund av skulderproblem

23. I vilken grad upplever du att dina skulderproblem påverkat idrottsprestationen under den senaste säsongen?

☐ Ingen påverkan

☐ I liten grad

☐ I måttlig grad

☐ I stor grad

☐ Ej kunnat deltaga, på grund av skulderproblem

24. I vilken grad har du upplevt smärta i skuldra under ditt idrottsutövande under den senaste säsongen?

☐ Ingen smärta

☐ I liten grad

☐ I måttlig grad

☐ I stor grad

Om du inte har upplevt några skulderproblem den senaste säsongen så gå direkt till fråga 33.

---

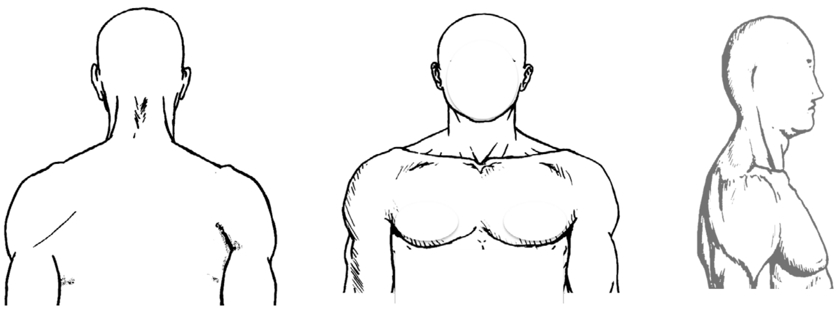
25. a. Hur uppstod skulderproblemen om du haft några den senaste säsongen?

☐ Gradvis tilltagande

☐ Vid ett specifikt tillfälle. b. Beskriv vid vilket tillfälle (exv. skott, drag i armen, fall på armen)

___

___



26. Var på skuldran har du upplevt problemen den senaste säsongen? (markera på bilden ovan. Du kan markera på flera områden)

27. Har dina skulderproblem påverkat dina dagliga aktiviteter i övrigt under den senaste säsongen (t.ex. lyfta, kamma håret)?

☐ Nej

☐ Ja

28. Har dina skulderproblem gjort att du haft svårt att sova under den senaste säsongen?

☐ Nej

☐ Ja

29. Har du känt dig stel i skuldran den senaste säsongen?

☐ Nej

☐ Ja

30. a. Har du sökt vård för dina skulderproblem den senaste säsongen?

☐ Nej

☐ Ja

b. Om Ja: Vem har du konsulterat? (Du kan kryssa i flera alternativ)

☐ Läkare

☐ Sjukgymnast

☐ Naprapat

☐ Kiropraktor

☐ Annan: c. Ange vem____

31. a. Har du fått någon diagnos på de skulderproblem du har haft under den senaste säsongen?

☐ Nej

☐ Ja

b. Om Ja: Vilken/vilka diagnos/diagnoser?__________________________________

32. a. Har du fått någon behandling för dina skulderproblem den senaste säsongen?

☐ Nej

☐ Ja:

b. Om Ja: Vilken behandling? (Du kan kryssa i flera alternativ)

☐ Massage

☐ Kortisonspruta

☐ Rehabövningar/träning för axel/skuldran

☐ Tejpning

☐ Läkemedel. c. Ange vilket ____

☐ Annat. d. Ange vad ____

Skulderproblem de senaste två månaderna

Nedanstående frågor gäller endast eventuella skulderproblem som du har haft under de senaste två månaderna, dvs. inte längre tillbaka i tiden än så, och även om du inte har några skulderproblem just nu.

Vänligen svara på alla frågor nedan oavsett om har haft besvär eller inte i skuldran. Välj det svarsalternativ som är mest passande för dig. Om du är osäker så försök att svara så gott du kan.

Med skulderproblem menas smärta, värk, stelhet, överrörlighet eller andra problem i axel och skuldra.

33. Har du under de senaste två månaderna haft svårigheter med att delta i din idrott (ordinarie träning/match/tävling) på grund av skulderproblem?

☐ Deltagit för fullt, utan skulderproblem

☐ Deltagit för fullt, men med skulderproblem

☐ Minskat deltagande, på grund av skulderproblem

☐ Ej kunnat deltaga, på grund av skulderproblem

34. I vilken grad har du under de senaste två månaderna minskat på träningsmängden på grund av dina skulderproblem?

☐ Ingen minskning

☐ I liten grad

☐ I måttlig grad

☐ I stor grad

☐ Ej kunnat deltaga, på grund av skulderproblem

35. I vilken grad upplever du att dina skulderproblem påverkat idrottsprestationen under de senaste två månaderna?

☐ Ingen påverkan

☐ I liten grad

☐ I måttlig grad

☐ I stor grad

☐ Ej kunnat deltaga, på grund av skulderproblem

36. I vilken grad har du upplevt smärta i skuldran under ditt idrottsutövande under de senaste två månaderna?

☐ Ingen smärta

☐ I liten grad

☐ I måttlig grad

☐ I stor grad

Om du inte har upplevt några skulderproblem de senaste två månaderna så gå direkt till fråga 45

---

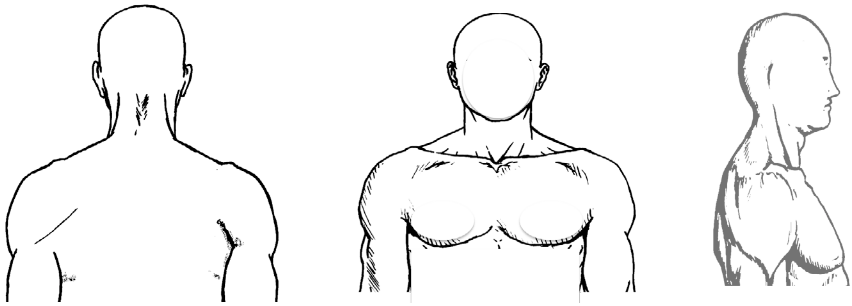
37. a. Hur uppstod skulderproblemen om du haft några de senaste två månaderna?

☐ Gradvis tilltagande

☐ Vid ett specifikt tillfälle. b. Beskriv vid vilket tillfälle (exv. skott, drag i armen, fall på armen)

____

____



38. Var på skuldran har du upplevt problemen de senaste två månaderna? (markera på bilden ovan. Du kan markera flera områden)

39. Har dina skulderproblem påverkat dina övriga dagliga aktiviteter de senaste två månaderna (t.ex. lyfta, kamma håret)?

☐ Nej

☐ Ja

40. Har dina skulderproblem gjort att du haft svårt att sova under de senaste två månaderna?

☐ Nej

☐ Ja

41. Har du känt dig stel skuldran under de senaste två månaderna?

☐ Nej

☐ Ja

42. a. Har du sökt vård för dina skulderproblem de senaste två månaderna?

☐ Nej

☐ Ja

b. Om Ja: Vem har du konsulterat? (Du kan kryssa i flera alternativ)

☐ Läkare

☐ Sjukgymnast

☐ Naprapat

☐ Kiropraktor

☐ Annan: c. Ange vem____

43. a. Har du fått någon diagnos på de skulderproblem du har haft under de senaste två månaderna?

☐ Nej

☐ Ja

b. Om Ja: Vilken/vilka diagnos/diagnoser?____________________________________

44. a. Har du fått någon behandling för dina skulderproblem de senaste två månaderna?

☐ Nej

☐ Ja

b. Om Ja: Vilken behandling? (Du kan kryssa i flera alternativ)

☐ Massage

☐ Kortisonspruta

☐ Läkemedel. c. Ange vilket ____

☐ Tejpning

☐ Rehabövningar/träning för axel/skuldran

☐ Annat. d. Ange vad ____

Här följer några påståenden som du ska ta ställning till på en 5-gradig skala, där 1 är ”stämmer inte alls” och 5 ”stämmer precis”.

		Stämmer inte alls				**Stämmer precis**
45.	Jag betraktar mig själv som en idrottare	1	2	3	4	5
46.	Jag har många mål som har samband med mitt idrottande	1	2	3	4	5
47.	De flesta av mina vänner idrottar	1	2	3	4	5
48.	Idrott är den viktigaste delen av mitt liv	1	2	3	4	5
49.	Jag tänker mer på idrott än på någonting annat	1	2	3	4	5
50.	Jag behöver träna och tävla för att känna mig nöjd med mig själv	1	2	3	4	5
51.	Andra människor betraktar mig i huvudsak som en idrottstyp	1	2	3	4	5
52.	Jag känner mig missnöjd med mig själv när jag presterar dåligt i min idrott	1	2	3	4	5
53.	Idrott är det enda viktiga i mitt liv	1	2	3	4	5
54.	Jag skulle bli mycket deprimerad om jag blev skadad så att jag inte kunde fortsätta att idrotta	1	2	3	4	5

APPENDIX B

Veckorapportering

Vi önskar att du svarar på alla frågor i formuläret även om du inte har/har haft problem med respektive kroppsdel. Gällande flervalsfrågor: svara med att sätta ett kryss i rutan för det bäst lämpade svarsalternativet, endast ett svarsalternativ per fråga. Om du inte är säker på vad du ska svara, försök ändå svara så gott du kan.

Veckoträning

1. Hur många **minuter** match har du spelat den senaste veckan? _________

2. Hur många **timmar** har du tränat handboll på handbollsplan den senaste veckan?____

3. Hur många **timmar** har du tränat handbollsinriktad träning som inte är handbollsspel den senaste veckan? (exv. fysträning, löpning, styrketräning) _________

Akut skada

4. Har du råkat ut för en akut skada i någon kroppsdel under de senaste sju dagarna? (*Med akut skada menas en plötslig händelse t.ex. stukning, fall eller sträckning).*

☐ Nej

☐ Ja

Om ja, viken kroppsdel?_____________________________________

Skulderproblem, akuta eller sådana som uppkommit tidigare

Med skulderproblem menas smärta, värk, stelhet, överrörlighet eller andra problem i axel och skuldra.

5. Har du haft svårigheter med att delta i din idrott (ordinarie träning/match/ tävling) på grund av skulderproblem den senaste veckan?

☐ Deltog för fullt, utan skulderproblem

☐ Deltog för fullt, men med skulderproblem

☐ Minskat deltagande, på grund av skulderproblem

☐ Kunde ej delta, på grund av skulderproblem

☐ Kunde ej delta/minskade deltagandet av annan orsak än skulderproblem, nämligen:

____

6. I vilken grad har du minskat på träningsmängden på grund av dina skulderproblem den senaste veckan?

- ☐ Ingen minskning
- ☐ I liten grad
- ☐ I måttlig grad
- ☐ I stor grad
- ☐ Kunde ej delta, på grund av skulderproblem

7. I vilken grad upplever du att dina skulderproblem påverkat idrottsprestationen den senaste veckan?

- ☐ Ingen påverkan
- ☐ I liten grad
- ☐ I måttlig grad
- ☐ I stor grad
- ☐ Kunde ej delta, på grund av skulderproblem

8. I vilken grad upplever du smärta i skuldran under ditt idrottsutövande den senaste veckan?

- ☐ Ingen smärta
- ☐ I liten grad
- ☐ I måttlig grad
- ☐ I stor grad

9. Vid besvär kryssa i vilken skuldra som du har/har haft, mest besvär i.

- ☐ Vänster
- ☐ Höger

____